

Exploring the Habitability of Icy Worlds: The Europa Jupiter System Mission

An artistic rendering of the Europa Jupiter System Mission. A spacecraft with a gold-colored body and multiple solar panels is shown in orbit around the icy moon of Europa. Europa is in the foreground, showing its cracked, icy surface. In the background, the large, banded planet Jupiter is visible, along with several other moons of the Jupiter system.

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A Joint NASA-ESA Outer Planet Mission Study

The Galilean Satellites

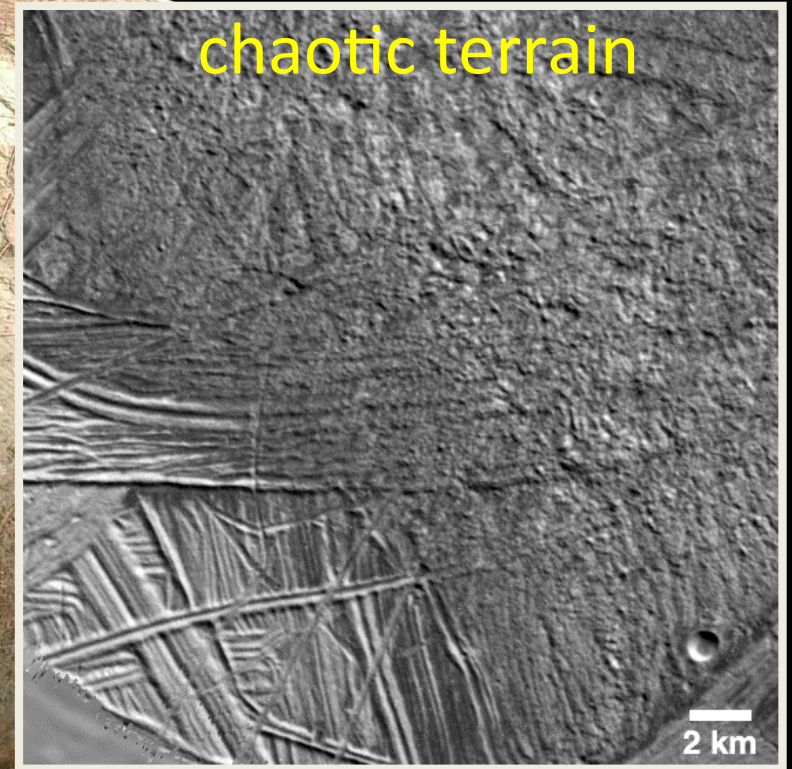
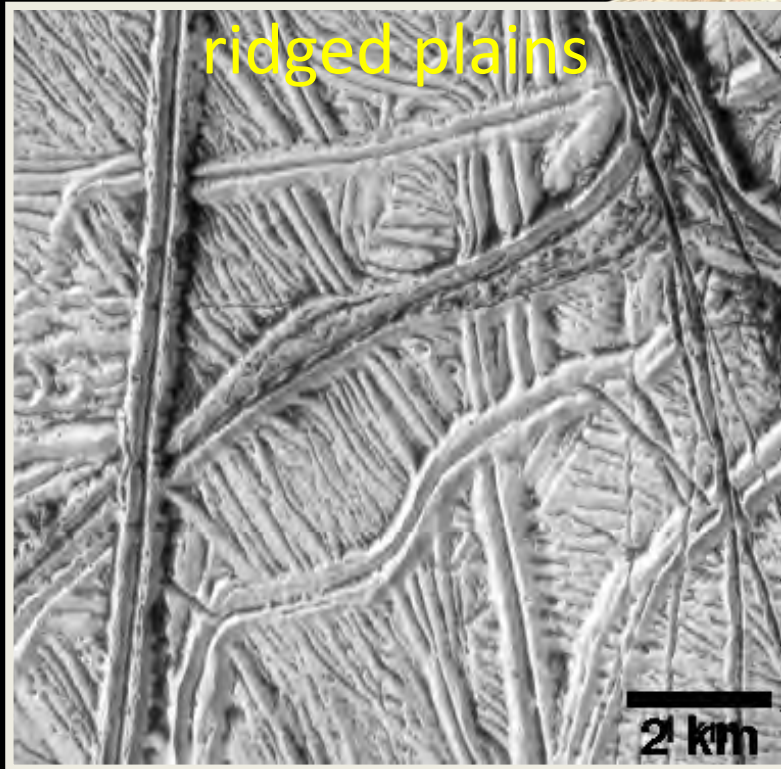


Galileo, 1610



Galileo, 1995-2003

Europa: Intriguing Geology

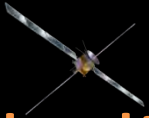


Ridged Plains

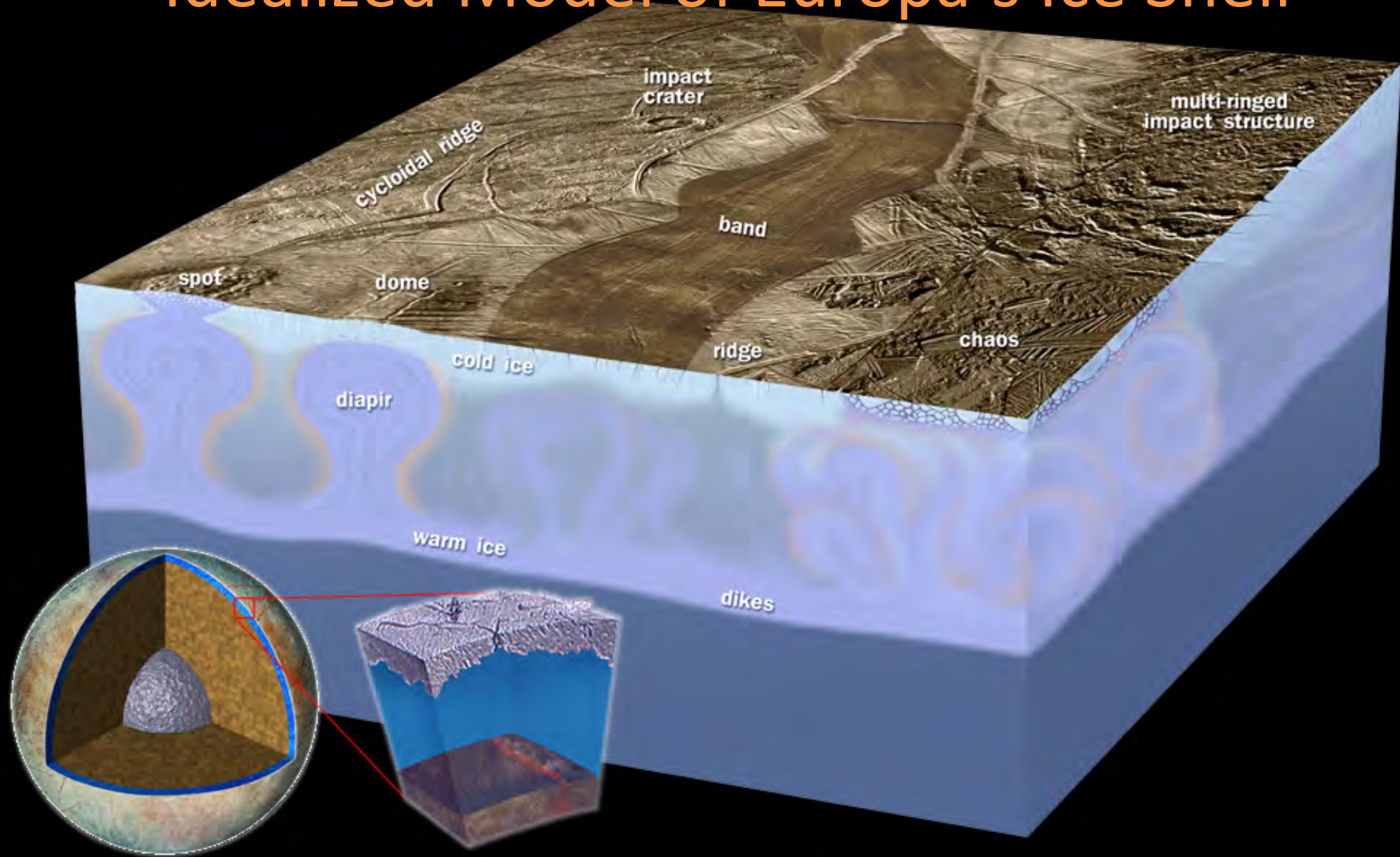


Conamara Chaos



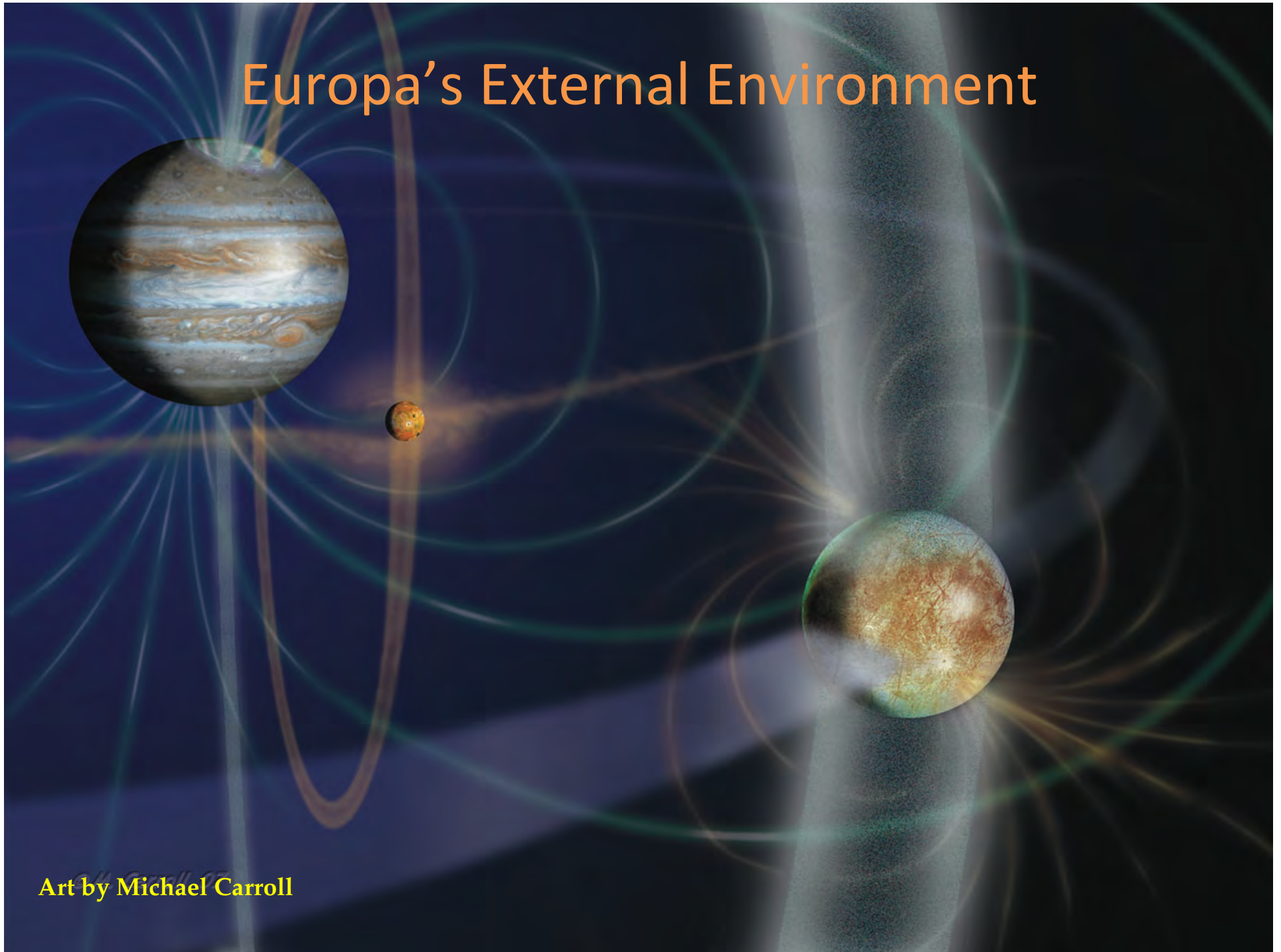


Idealized Model of Europa's Ice Shell

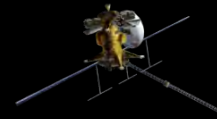
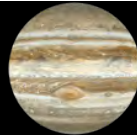
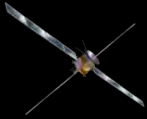


Europa is the archetype for understanding icy satellite habitability and complex interrelated geophysical processes.

Europa's External Environment

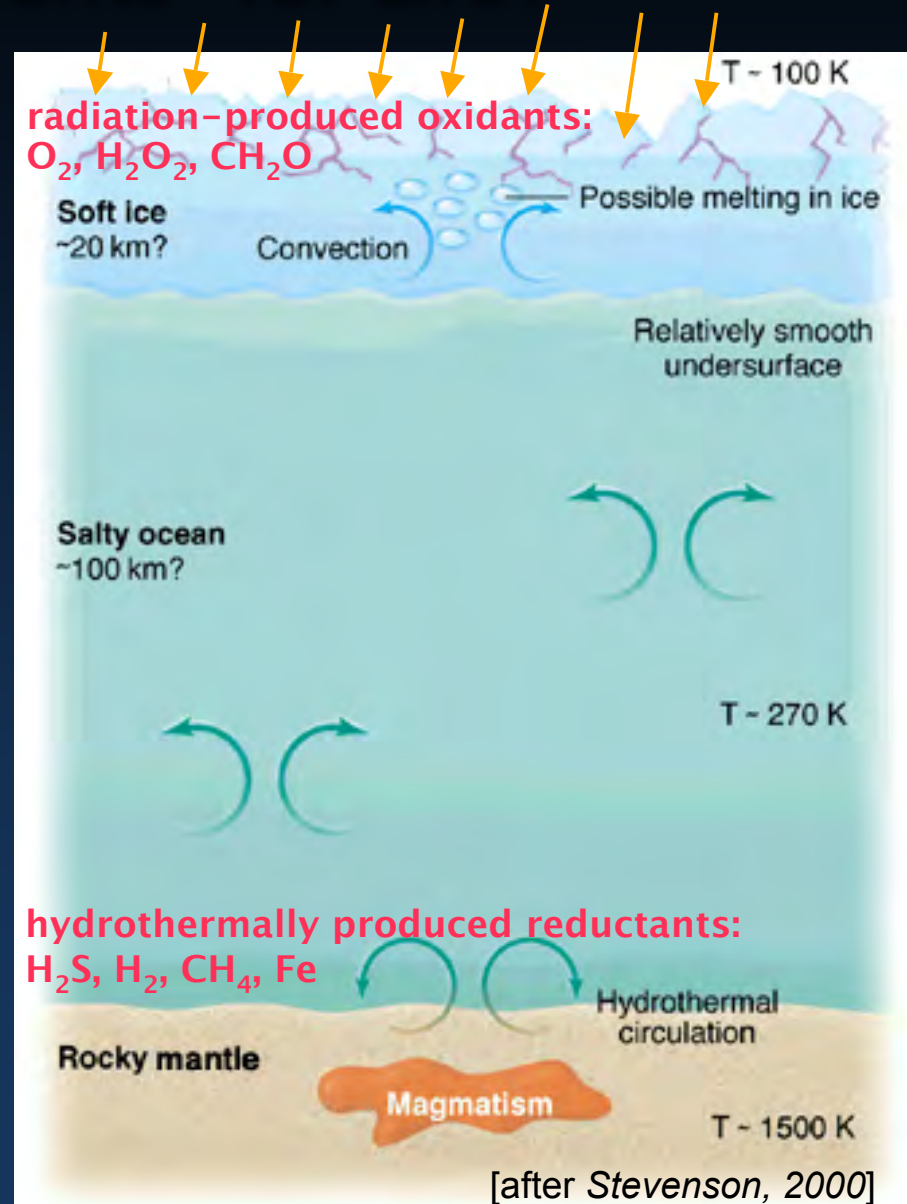


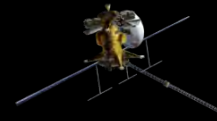
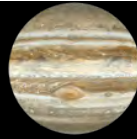
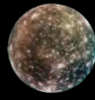
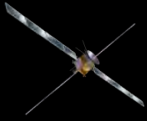
Art by Michael Carroll



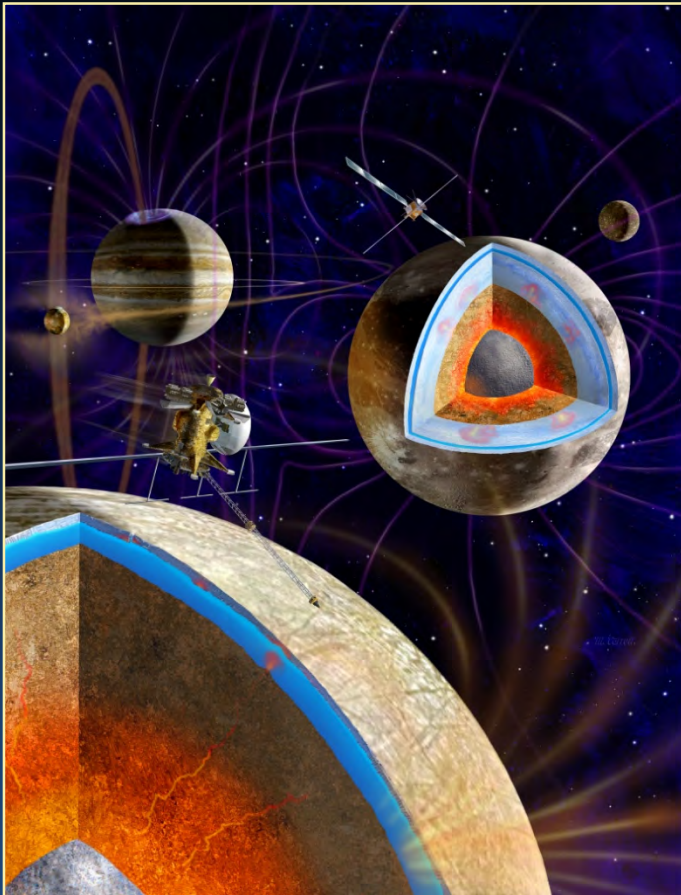
Europa: “Ingredients” for Life? e^- , O^+ , S^+ , ...

- Water:
 - Warm salty H_2O ocean.
- Essential elements:
 - Accretion of CO_2 ?
 - Impactors.
 - But radiation destroys organics in upper ~10s cm of ice.
- Chemical energy:
 - Radiation of $H_2O \Rightarrow$ oxidants.
 - Mantle contact: serpentinization and possible hydrothermal activity.
- Relatively stable environment:
 - Large satellite retains heat.
 - But activity might not be steady-state.

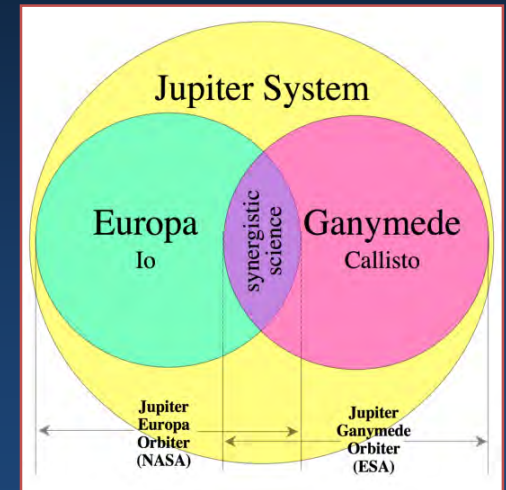




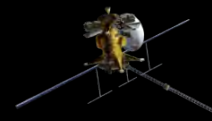
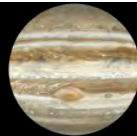
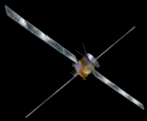
Europa Jupiter Science Mission (EJSM)



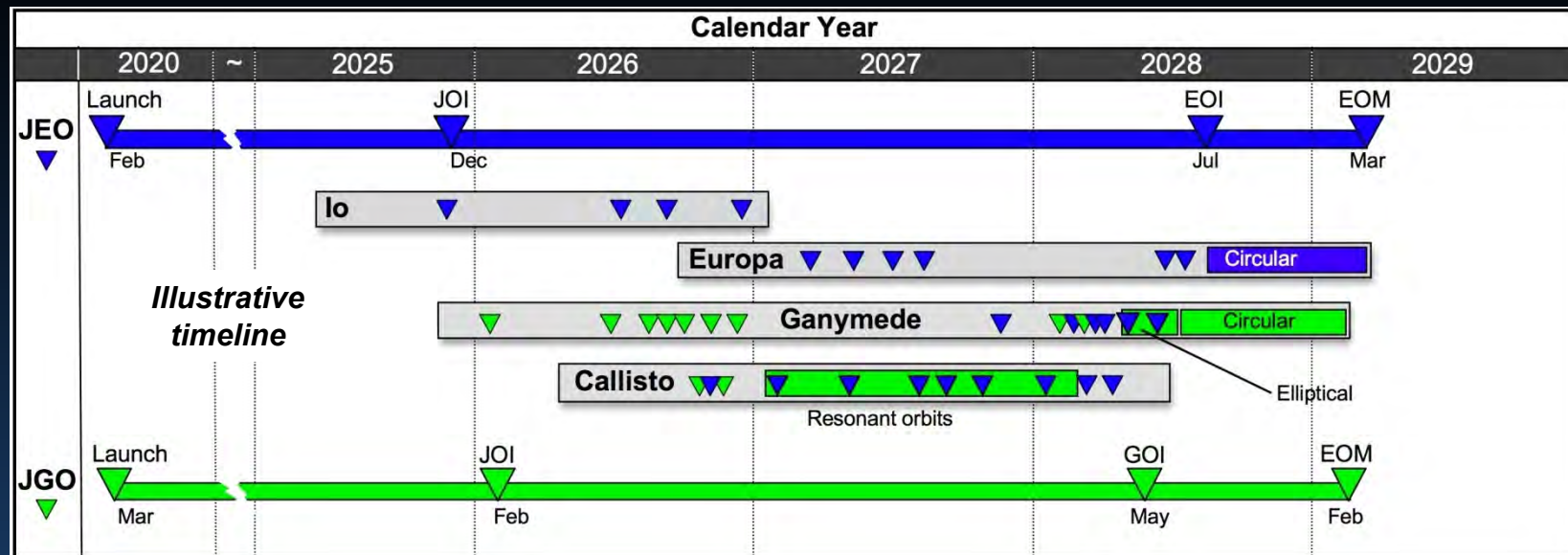
- NASA and ESA: Shared mission leadership
- Independently launched and operated orbiters
 - NASA-led Jupiter Europa Orbiter (JEO)
 - ESA-led Jupiter Ganymede Orbiter (JGO)
- Complementary science and payloads
 - JEO concentrates on Europa and Io
 - JGO concentrates on Ganymede and Callisto
 - Synergistic overlap
 - 11-12 instruments each
- Science goals:
 - Icy world habitability
 - Jupiter system processes



Synergistic science: The sum of JEO + JGO is greater than the parts

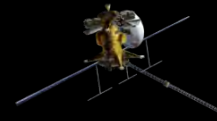
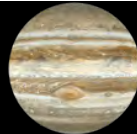
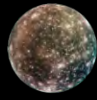
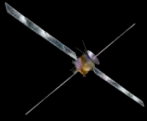


Nominal EJSM Timeline



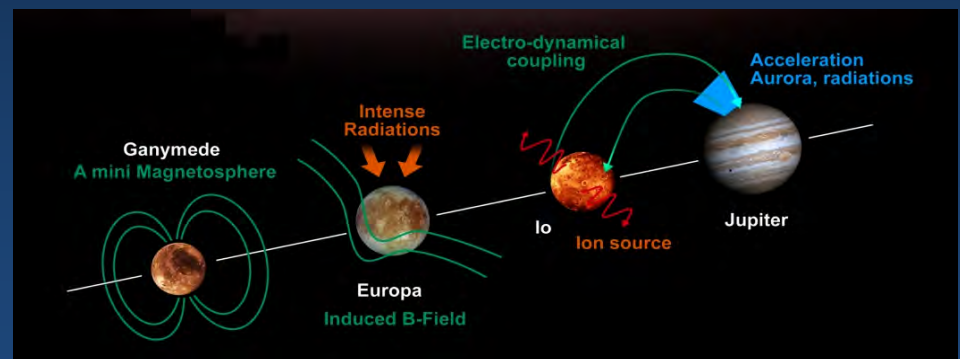
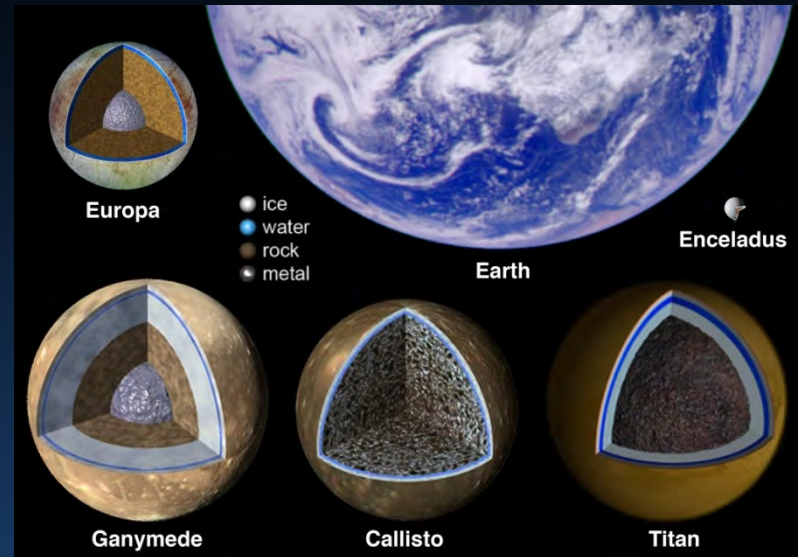
- Launches: 2020
- Jovian system tour phases: 2–3 years
- Moon orbital phases: 6–12 months
- End of Prime Missions: 2029
- Flexibility if either flight element is delayed or advanced

Coordinated timelines ensure synergistic science

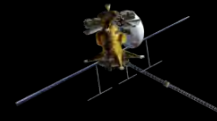
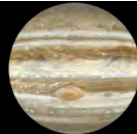
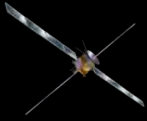


EJSM Theme: The Emergence of Habitable Worlds Around Gas Giants

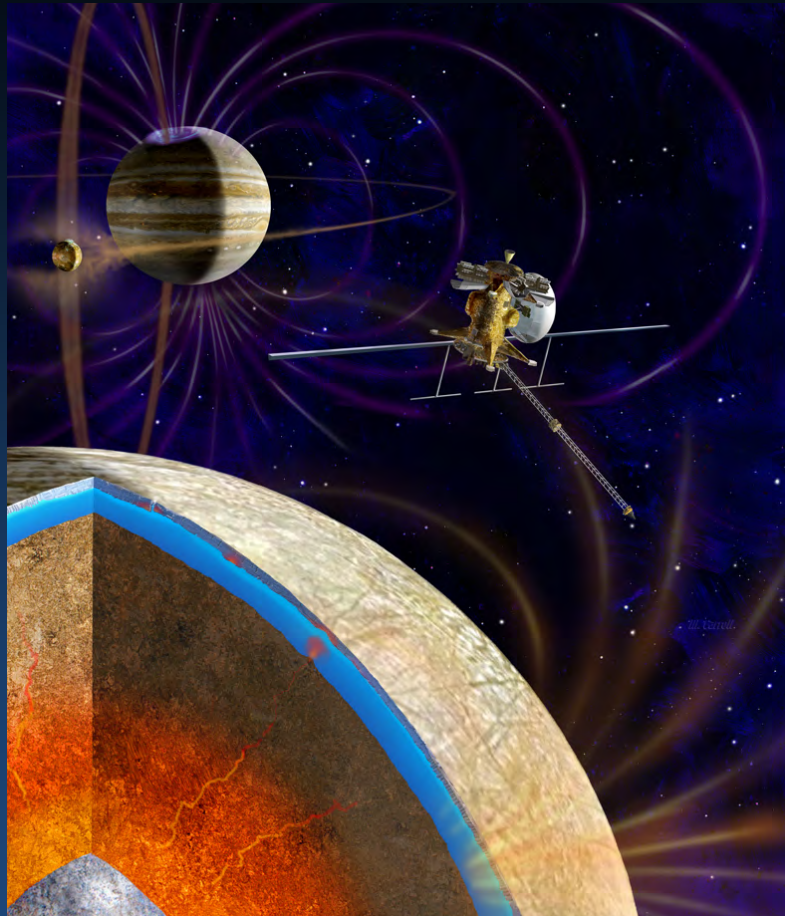
- *Goal 1:* Determine if the Jupiter system harbors habitable worlds
 - Ocean characteristics
 - Ice shells and subsurface water
 - Deep internal structure, and (for Ganymede) intrinsic magnetic field
 - External environments
 - Global surface compositions
 - Surface features and future landing sites
- *Goal 2:* Characterize Jupiter system processes
 - Satellite system
 - Jupiter atmosphere
 - Magnetodisk/magnetosphere
 - Jovian system Interactions
 - Jovian system origin



Emphasis on icy moon habitability and Jupiter system processes



JEO Goal: Explore Europa to Investigate Its Habitability

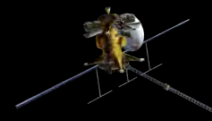
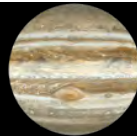
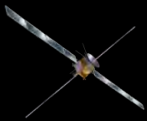


Habitability

Objectives (prioritized):

- Ocean and Interior
- Ice Shell
- Chemistry and Composition
- Geology and Landing Sites
- Jupiter System
 - Satellite surfaces and interiors
 - Satellite atmospheres
 - Plasma and magnetospheres
 - Jupiter atmosphere
 - Rings

Characterizing the archetype of icy world habitability



JEO Model Payload

Ocean

Laser Altimeter

LA

Radio Science

RS

Ice

Ice Penetrating Radar

IPR

Chemistry

Vis-IR Imaging Spectrometer

VIRIS

UV Spectrometer

UVS

Ion and Neutral Mass Spectrometer

INMS

Geology

Thermal Instrument

TI

Narrow Angle Camera

NAC

Wide Angle Camera and Medium Angle Camera

WAC + MAC

Fields and Particles

Magnetometer

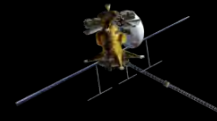
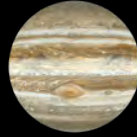
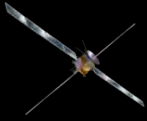
MAG

Particle and Plasma Instrument

PPI

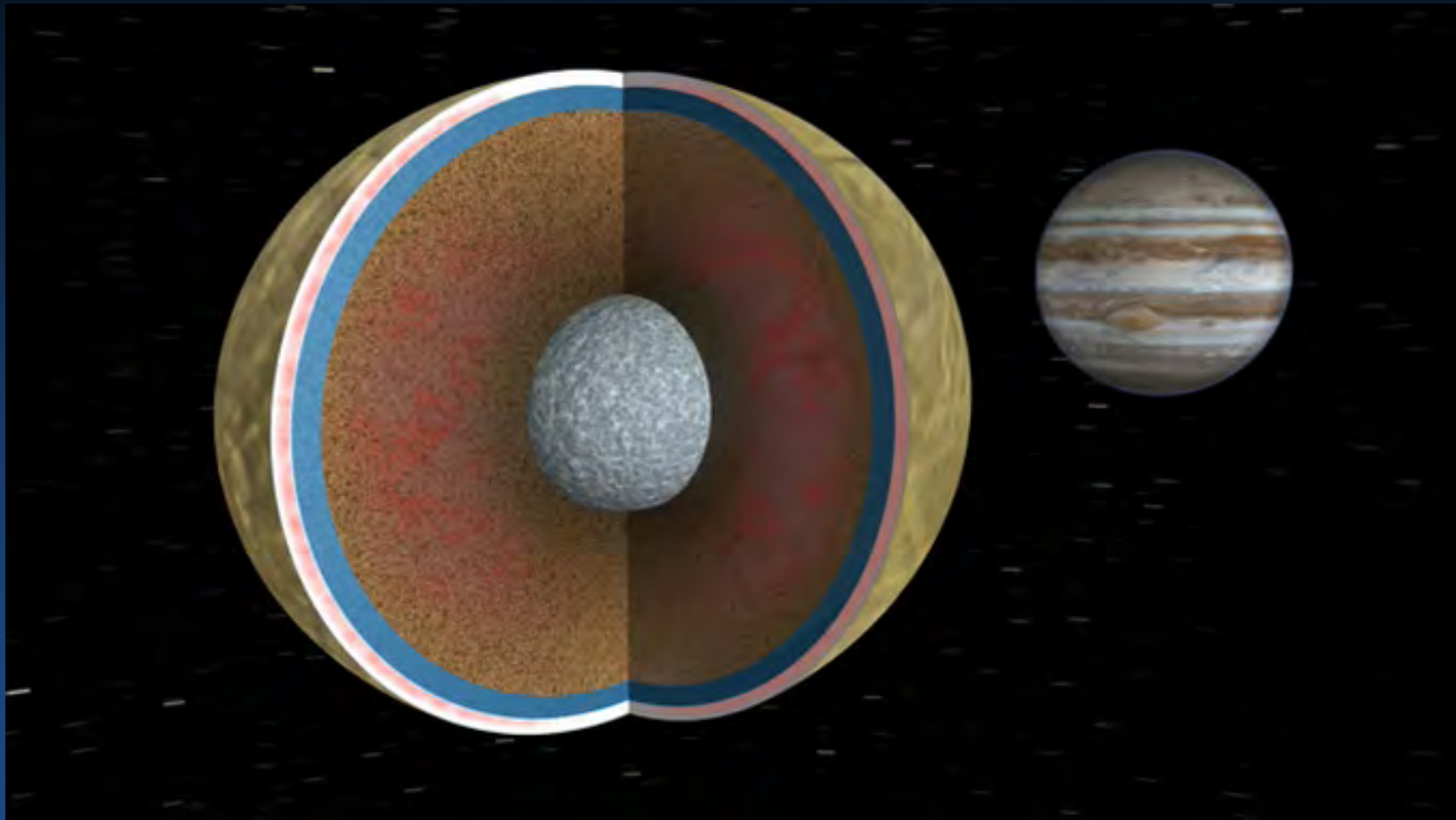
- Model payload is a proof-of-concept example
 - Other instrument choices may be viable
- Emphasizes accomplishing Europa investigations
- Enables robust Jupiter system science
- The final selected payload will almost certainly be different

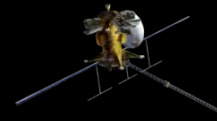
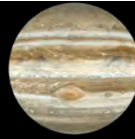
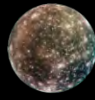
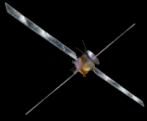
Capable model payload with a conservative approach



Europa: Ocean • Ice • Chemistry • Geology

A. Characterize the extent of the ocean and its relation to the deeper interior.

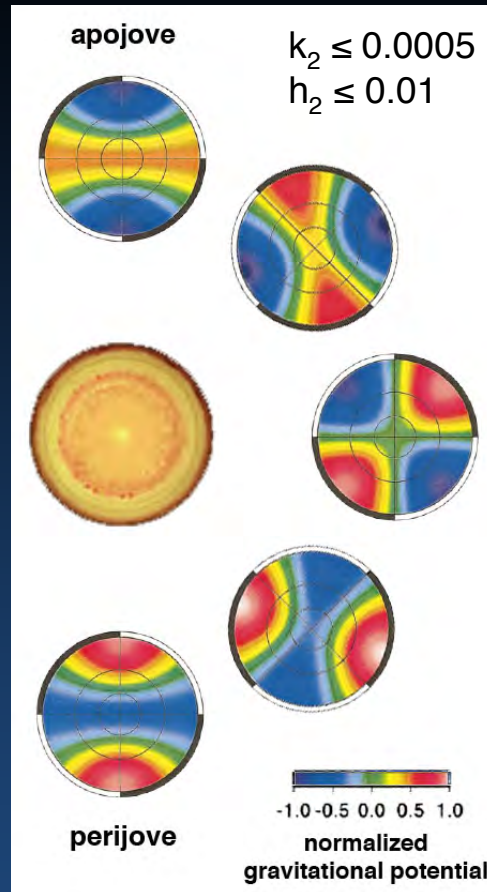




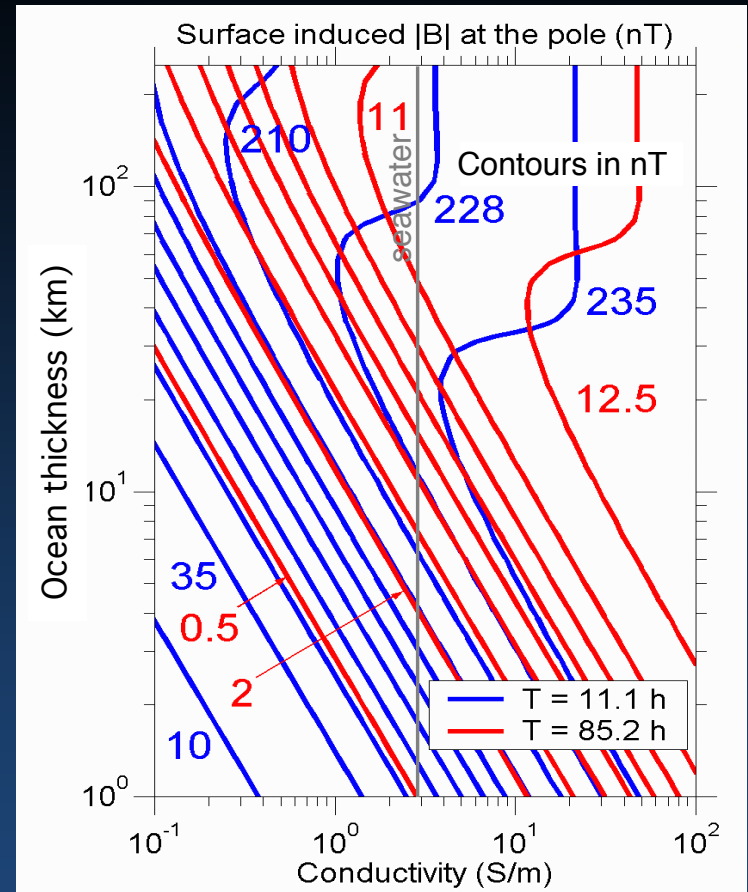
Europa: Ocean • Ice • Chemistry • Geology

A. Ocean & deeper interior:

- Gravitational tides
- Magnetic environment (including plasma)
- Surface motion
- Dynamical rotation state
- Core, rocky mantle, & rock-ocean interface

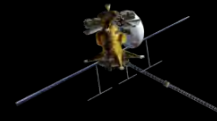
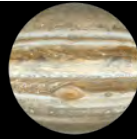
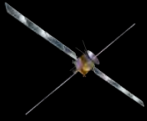


[Moore & Schubert, 2000]

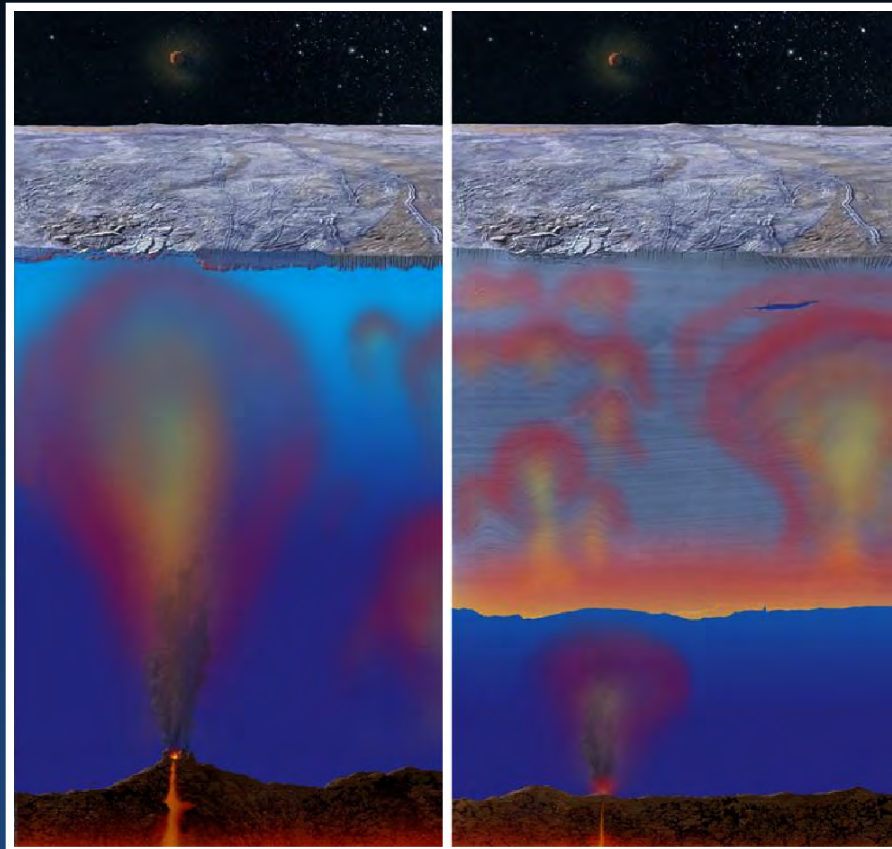


[Khurana, 2002]

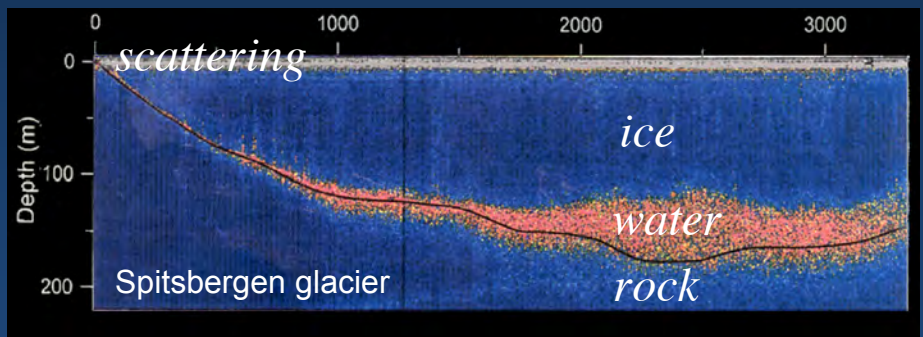
Geophysical techniques reveal the nature of the interior



Europa: Ocean • Ice • Chemistry • Geology

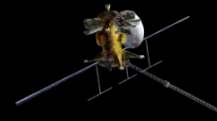
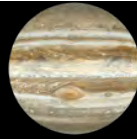
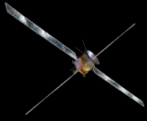


B. Characterize the ice shell and any subsurface water, including their heterogeneity, and the nature of surface-ice-ocean exchange



[Bjornsson et al., 1996]

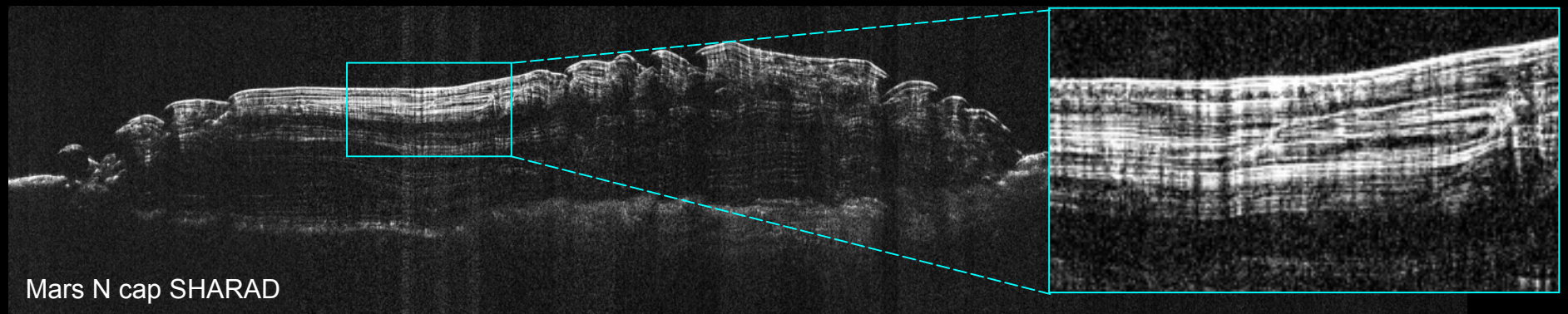
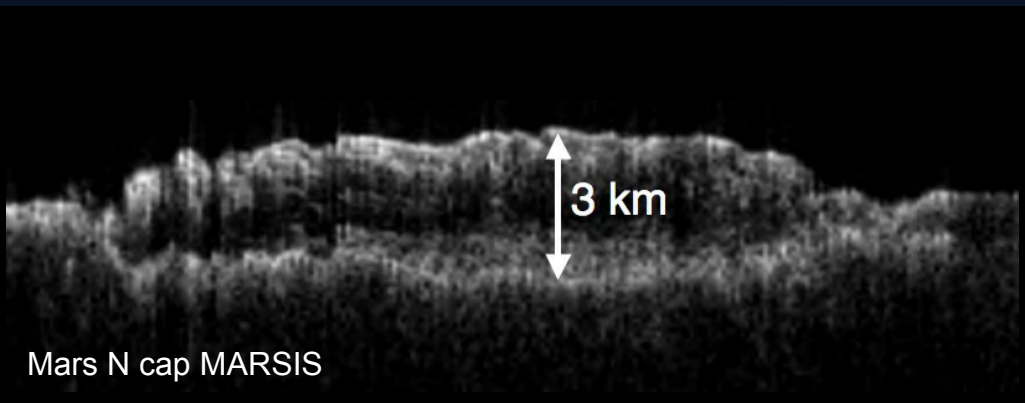
Exchange processes are critical to Europa's habitability



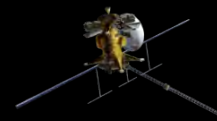
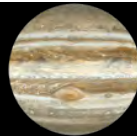
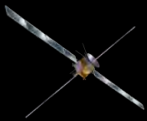
Europa: Ocean • Ice • Chemistry • Geology

B. Ice shell & subsurface water:

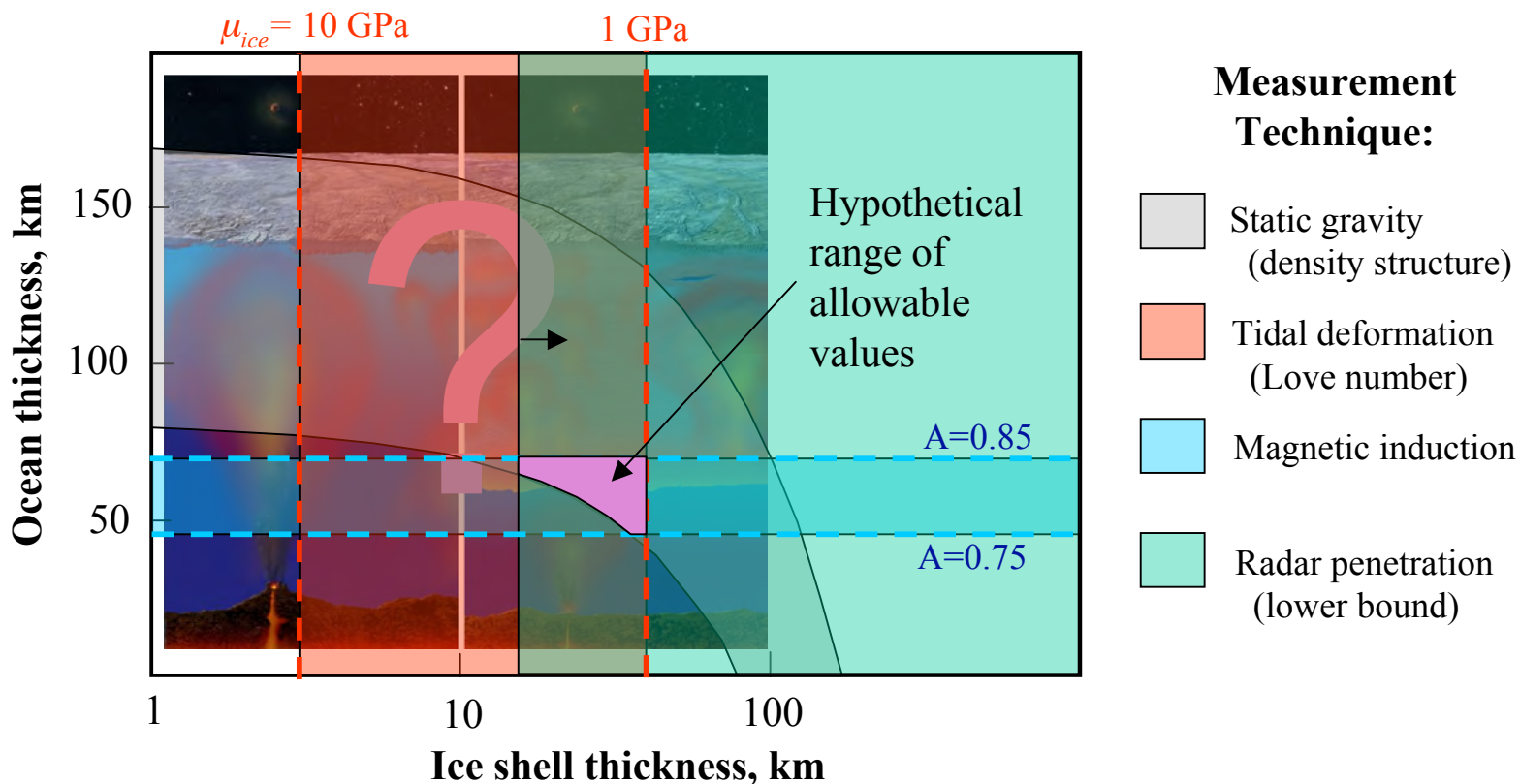
- Shallow water
- Ice-ocean interface
- Material exchange
- Heat flow variations



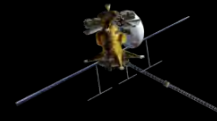
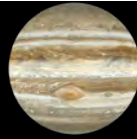
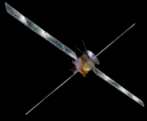
Radar sounding would characterize the ice shell in 3 dimensions



Constraining Ice Shell Thickness: *Hypothetical Example*



Multiple techniques constrain ice shell thickness

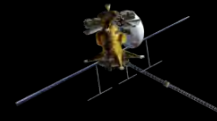
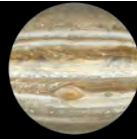
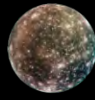
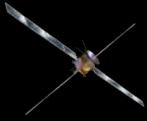


Europa: Ocean • Ice • Chemistry • Geology

C. Determine global surface compositions and chemistry, especially as related to habitability



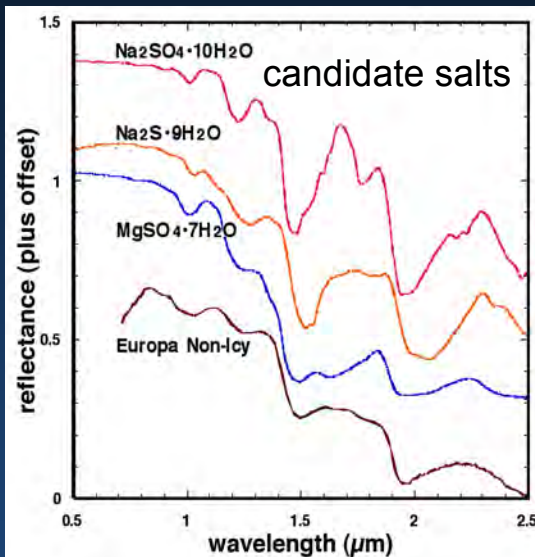
Composition is key to understanding ocean habitability



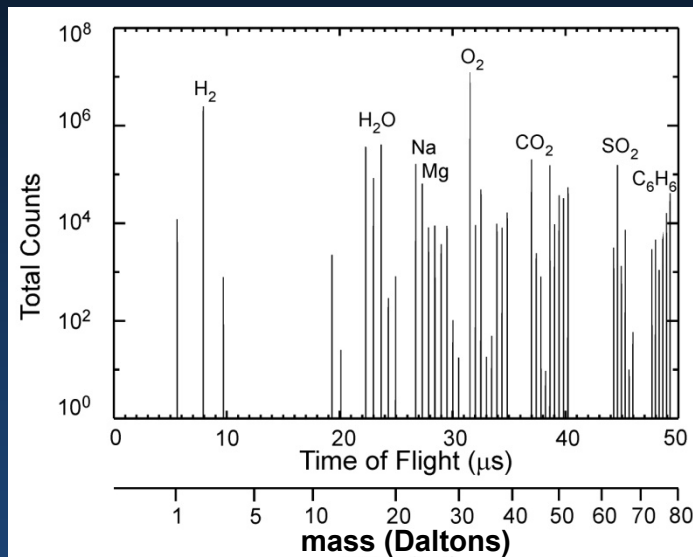
Europa: Ocean • Ice • Chemistry • Geology

C. Global surface composition & chemistry:

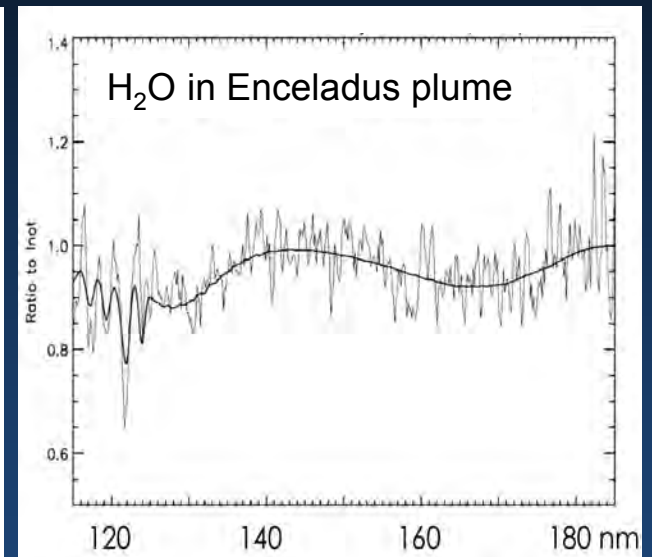
- Organic & inorganic chemistry
- Radiation effects
- Relation to geologic processes
- Exogenic materials



IR spectroscopy:
surface constituents

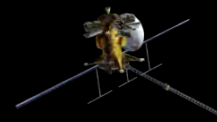
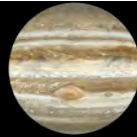
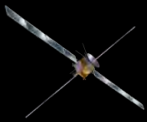


INMS:
sputtered particles



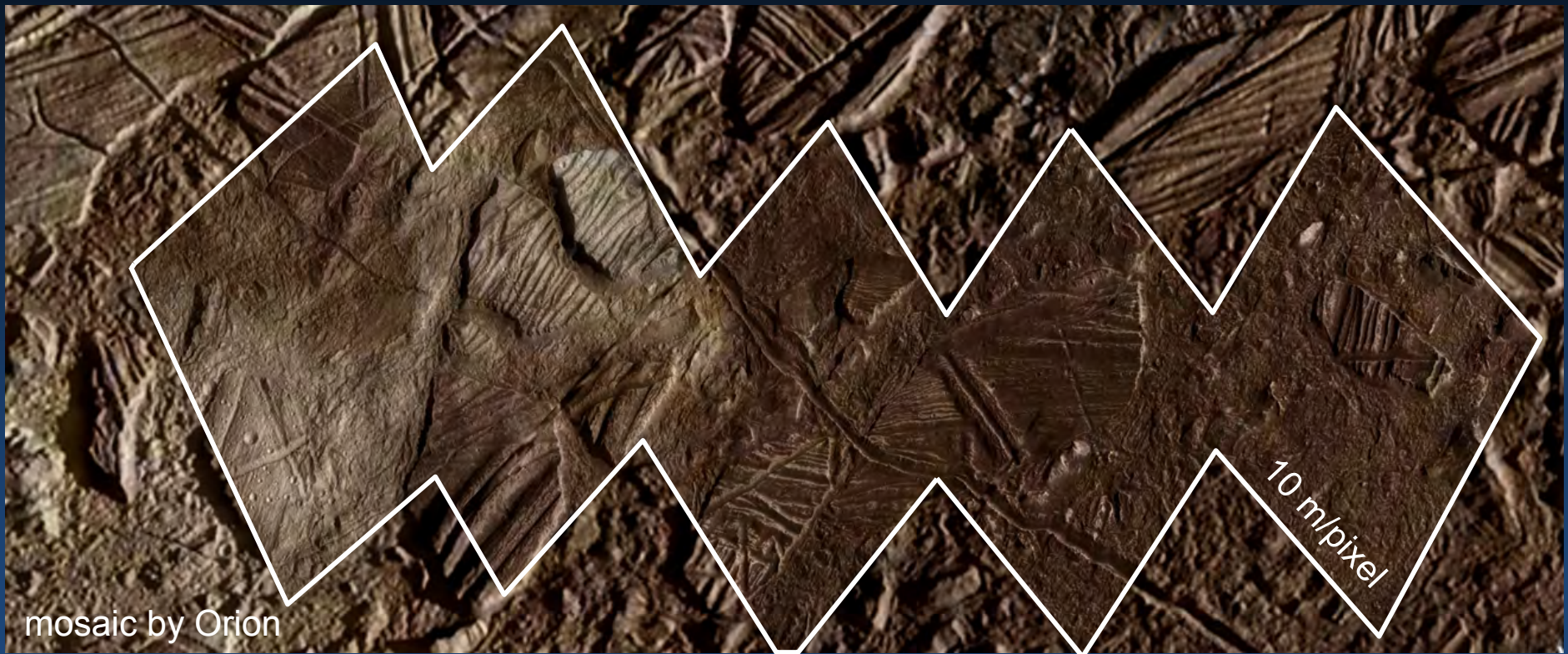
Stellar occultations:
atmospheric species

Multiple techniques characterize and map composition

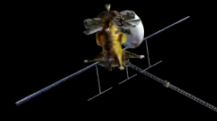
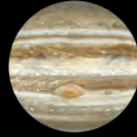
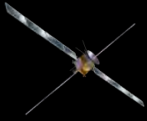


Europa: Ocean • Ice • Chemistry • Geology

D. Understand the formation of surface features, including sites of recent or current activity, and identify and characterize candidate sites for future in situ exploration



JEO would increase 10-20 m/pixel image coverage from 0.03% to 7%

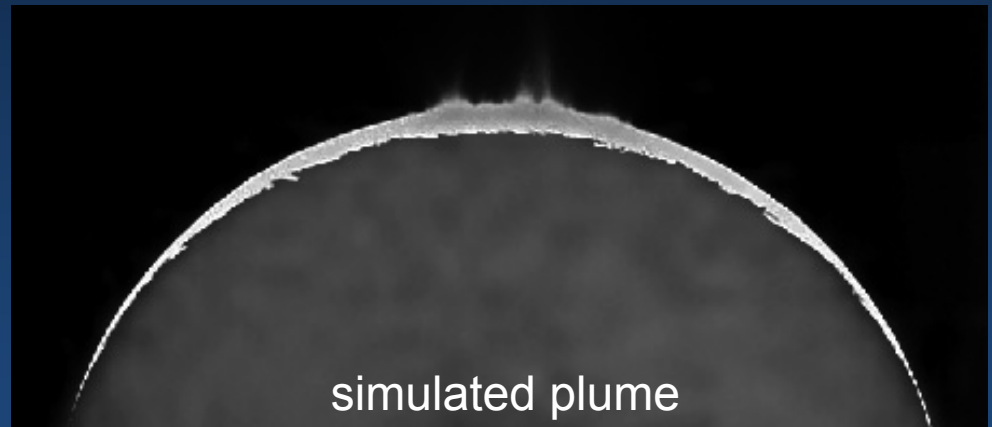


Europa: Ocean • Ice • Chemistry • Geology

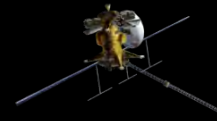
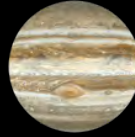
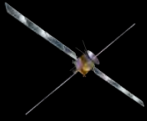


D. Surface features, activity, & landing sites:

- Formation history & 3-D character
- Recent activity & potential future landing sites
- Erosion & deposition

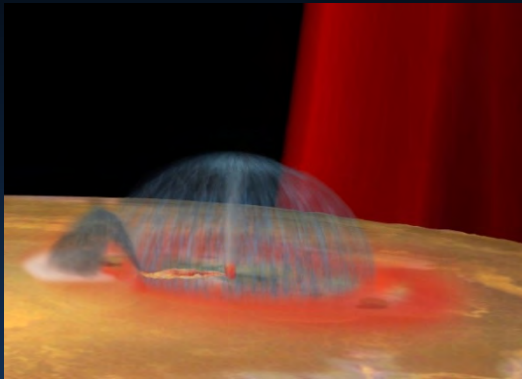


JEO would decipher Europa's varied and complex geology

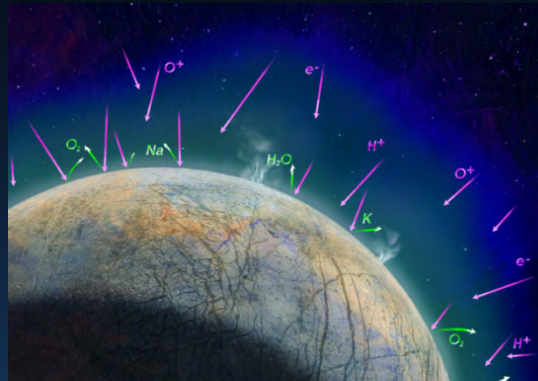


Jupiter System: Sats • Atm • Mag • Jupiter • Rings

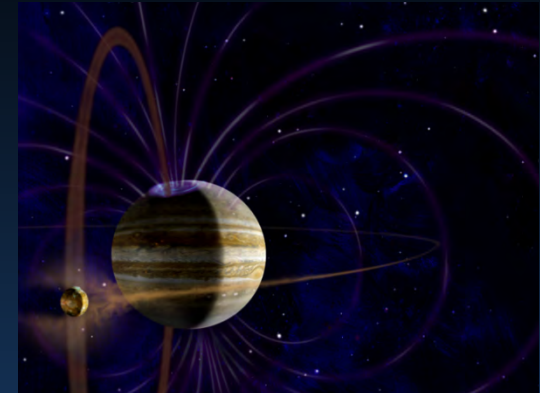
E. Understand Europa in the context of the Jupiter system



Satellite surfaces & interiors



Satellite atmospheres



Plasma & magnetospheres

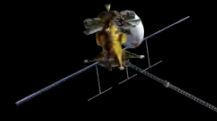
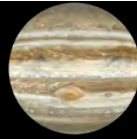
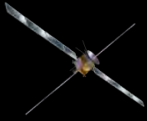


Jupiter atmosphere



Rings

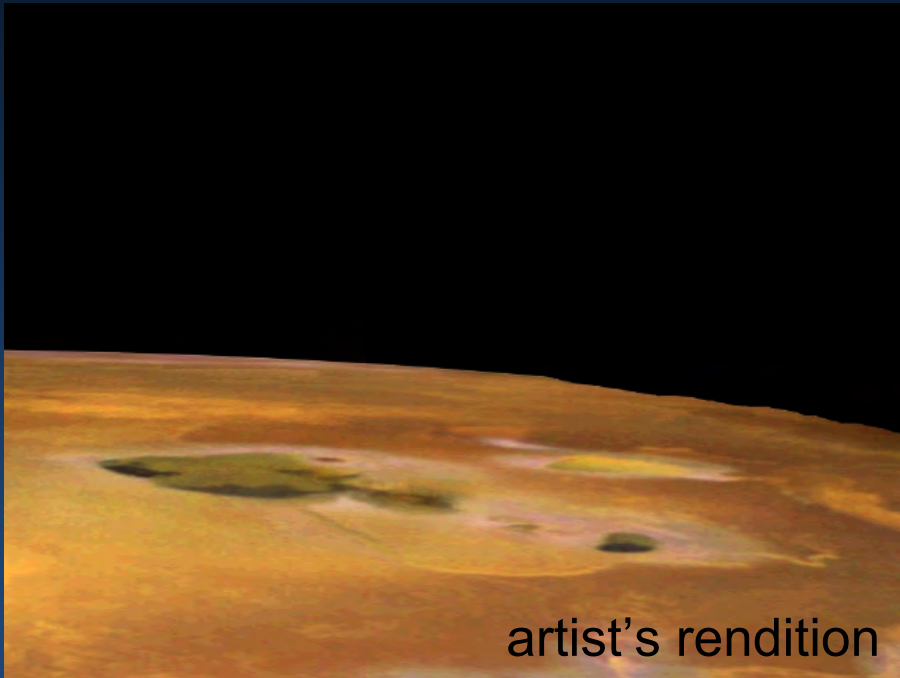
The Jupiter system is rich in dynamic and coupled processes



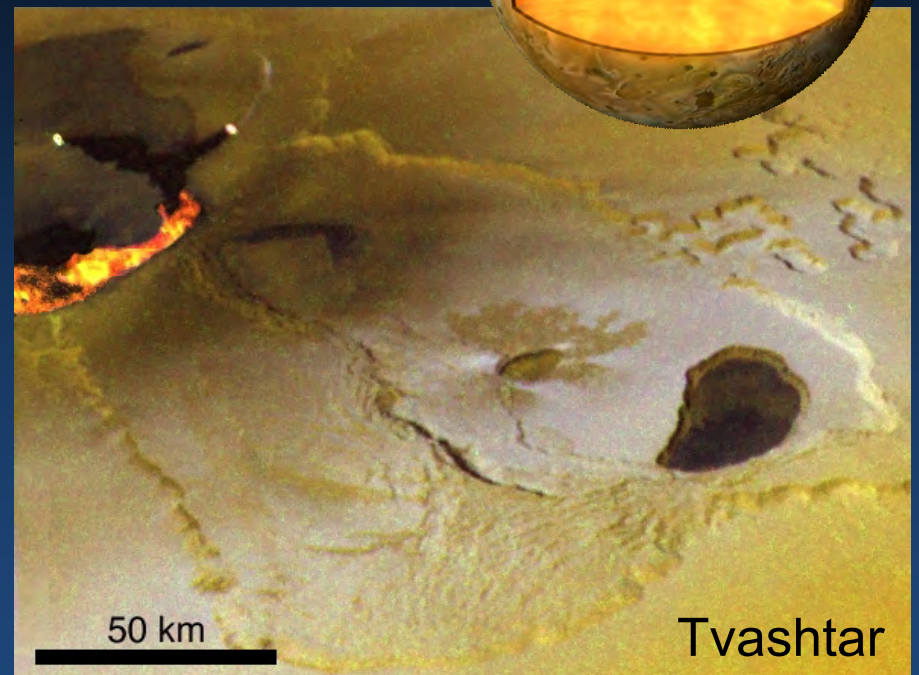
Jupiter System: Sats • Atm • Mag • Jupiter • Rings

Satellite surfaces & interiors:

- Io's tidal heating & heat loss
- Io's active volcanism



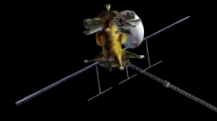
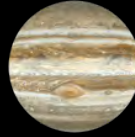
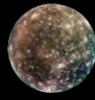
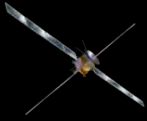
artist's rendition



50 km

Tvashtar

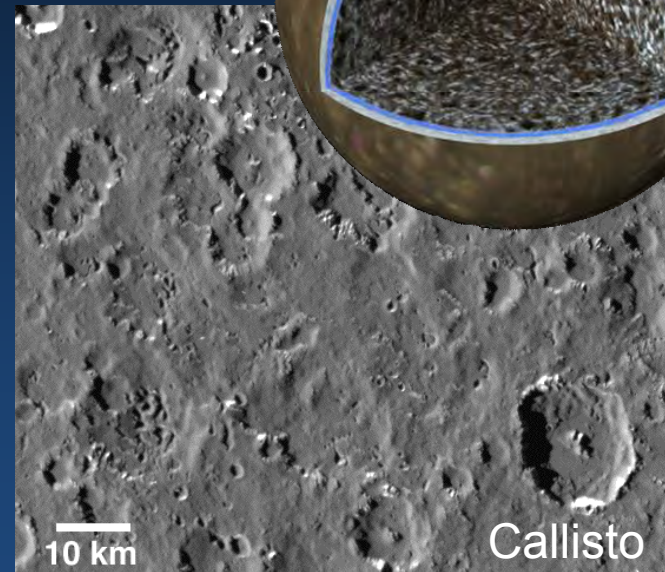
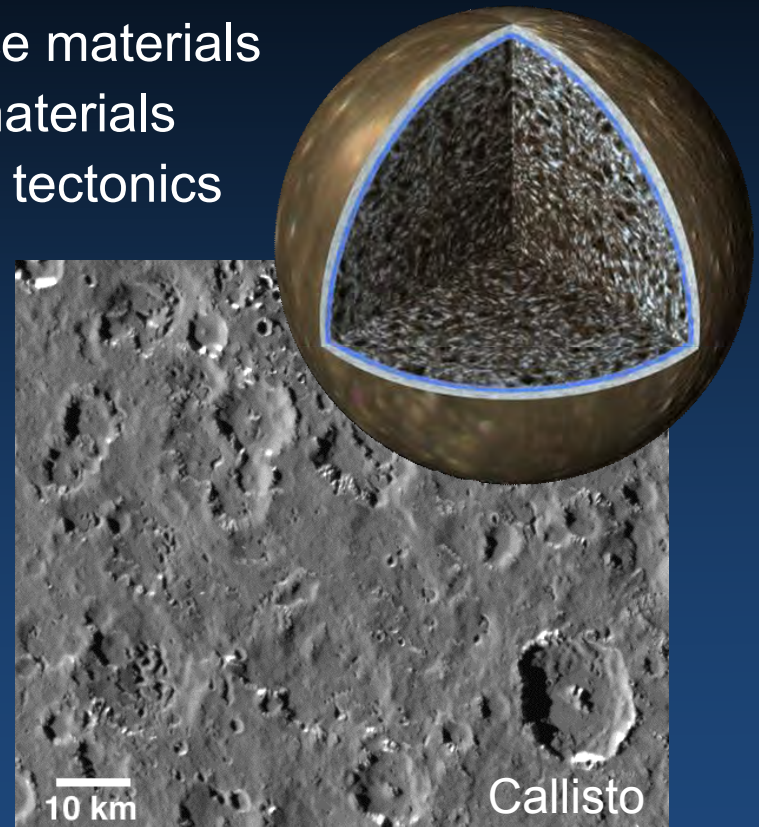
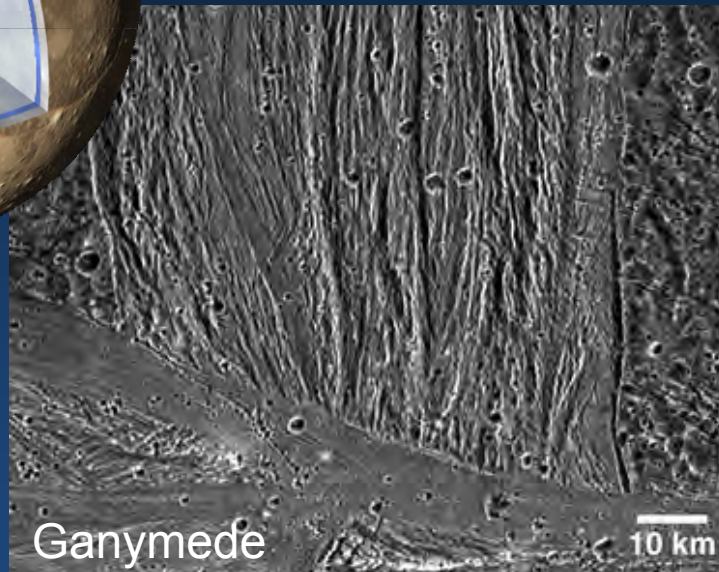
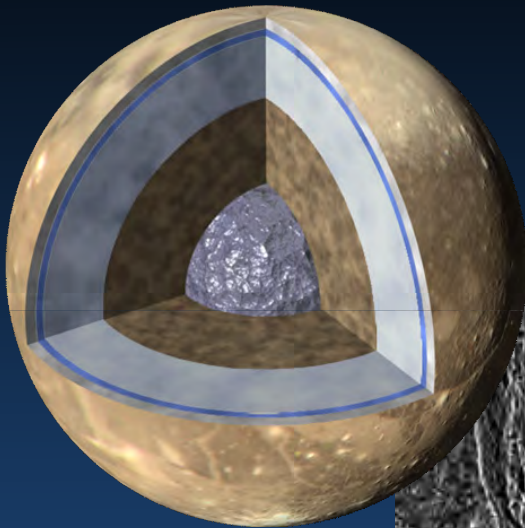
Io is the tidal engine of the Laplace resonance



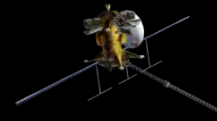
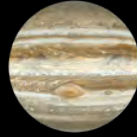
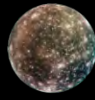
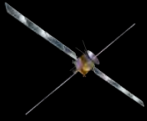
Jupiter System: Sats • Atm • Mag • Jupiter • Rings

Satellite surfaces & interiors (cont.):

- Water in Ganymede & Callisto
- Ganymede's surface materials
- Callisto's surface materials
- Internal evolution & tectonics



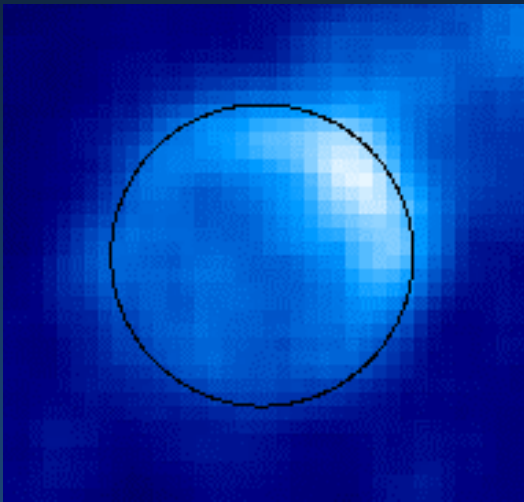
The icy Galilean satellites provide context for Europa



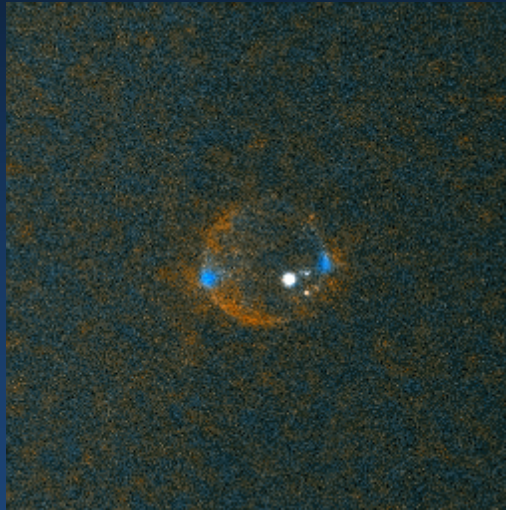
Jupiter System: Sats • Atm • Mag • Jupiter • Rings

Satellite atmospheres:

- Europa: Composition, variability, and dynamics
- Io: Composition, sources, and evolution
- Ganymede and Callisto: Sources and sinks



Europa atm. (HST O 1356Å)

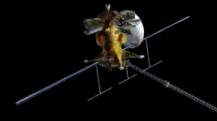
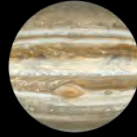
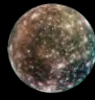
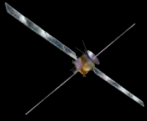


Io atm. & aurora (Cassini)



Ganymede aurora (HST)

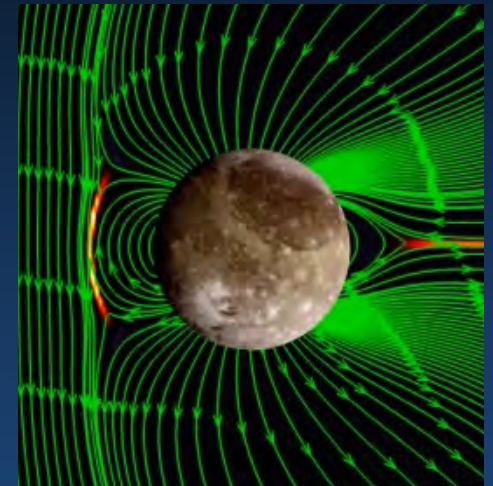
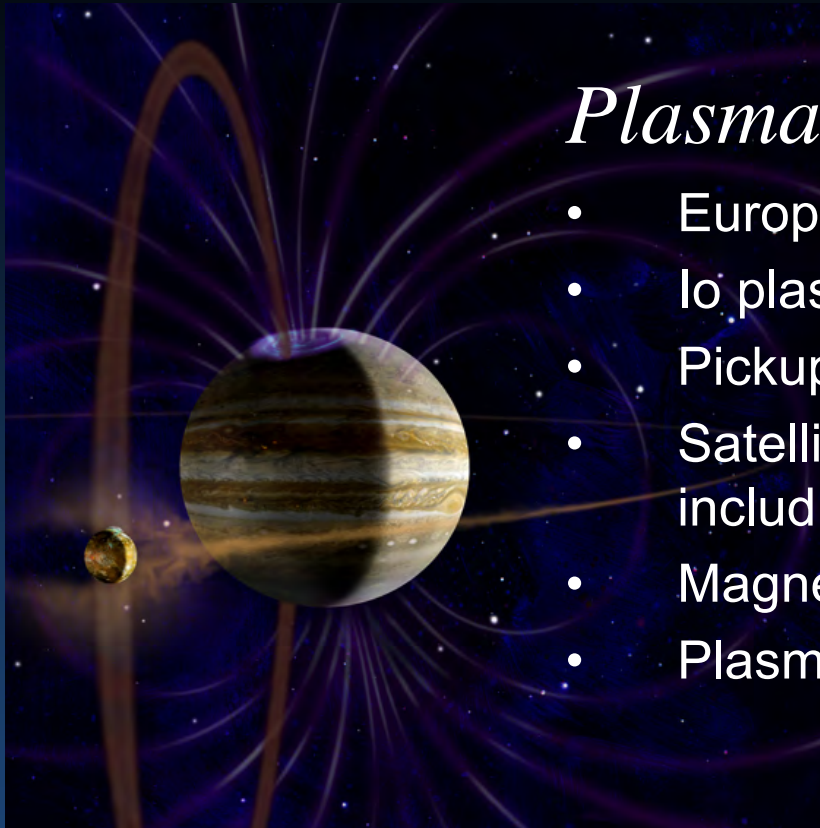
Understanding atmospheric interactions and processes



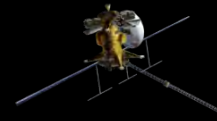
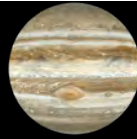
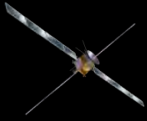
Jupiter System: Sats • Atm • Mag • Jupiter • Rings

Plasma & magnetospheres:

- Europa's escaping neutrals
- Io plasma torus
- Pickup & charge exchange
- Satellite interactions including Ganymede's field
- Magnetospheric structure
- Plasma transport



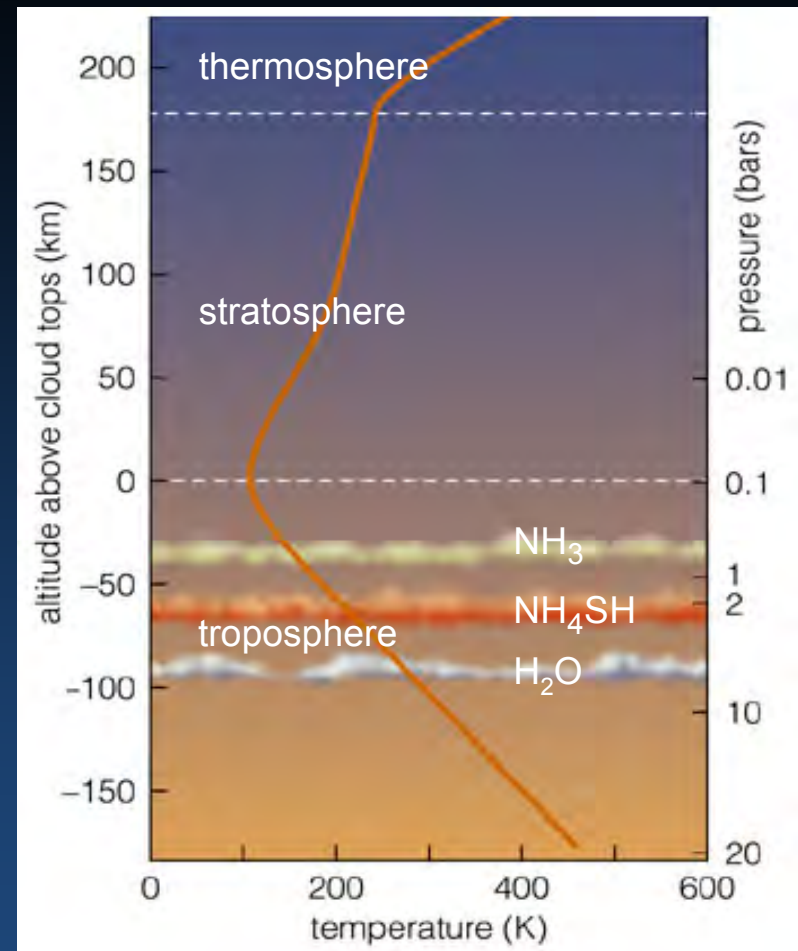
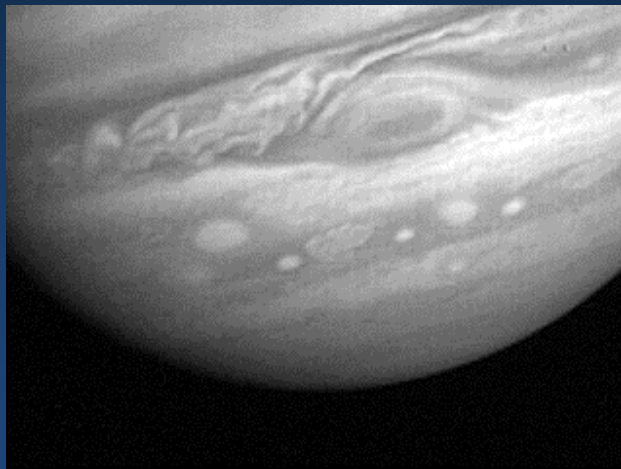
*Probing the Solar System's largest magnetosphere
and its unique satellite-magnetosphere interactions*



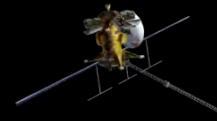
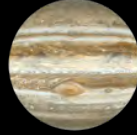
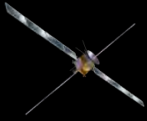
Jupiter System: Sats • Atm • Mag • Jupiter • Rings

Jupiter atmosphere:

- Atmospheric dynamics & circulation
- Atmospheric composition & chemistry
- Atmospheric vertical structure



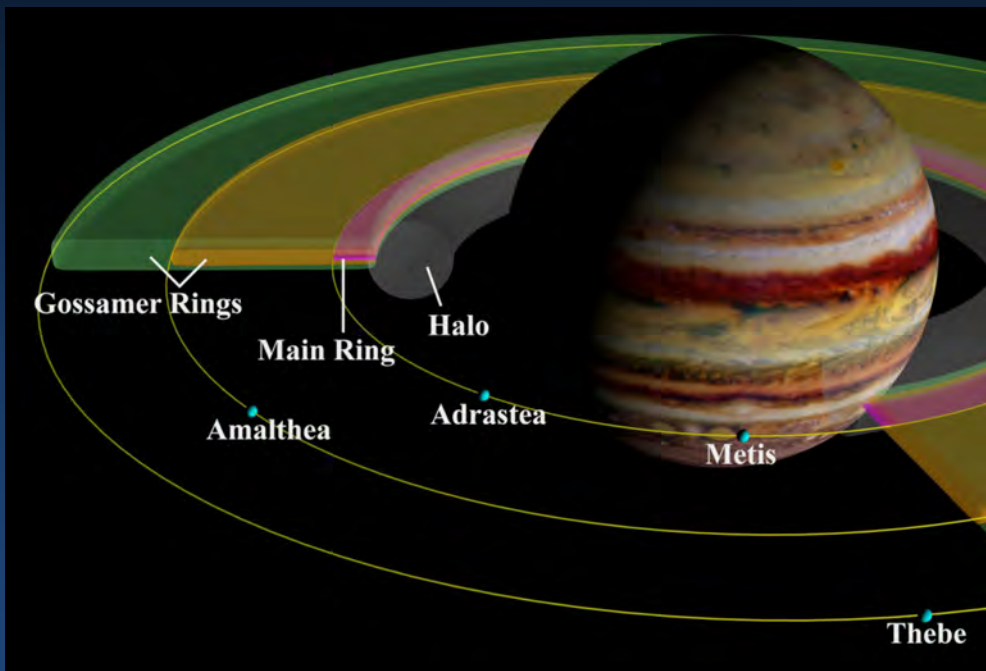
Addresses unanswered questions and complements Juno



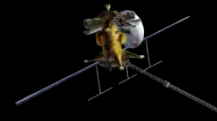
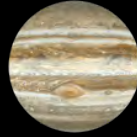
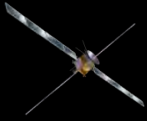
Jupiter System: Sats • Atm • Mag • Jupiter • Rings

Rings:

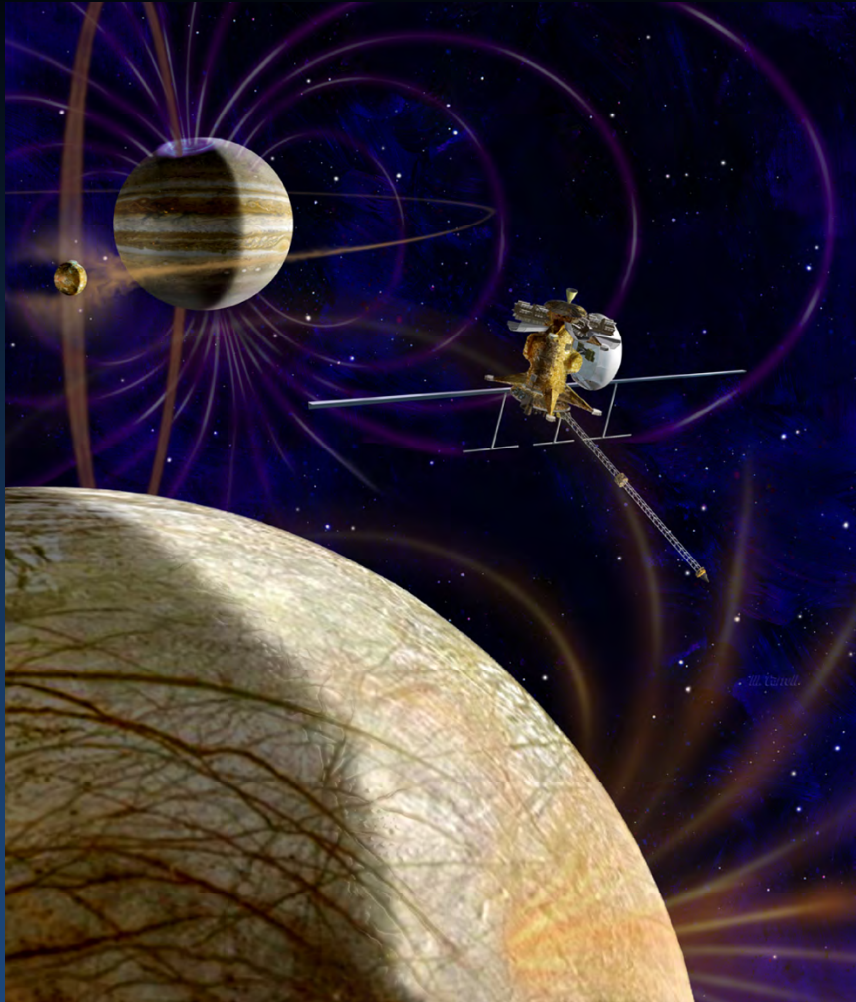
- Ring source bodies
- Dynamical processes



Comparative studies of ring dynamics and evolution



Jupiter Europa Orbiter Science

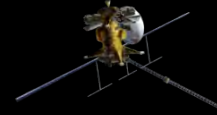
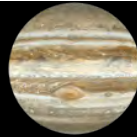
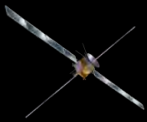


Habitability

Objectives Summary:

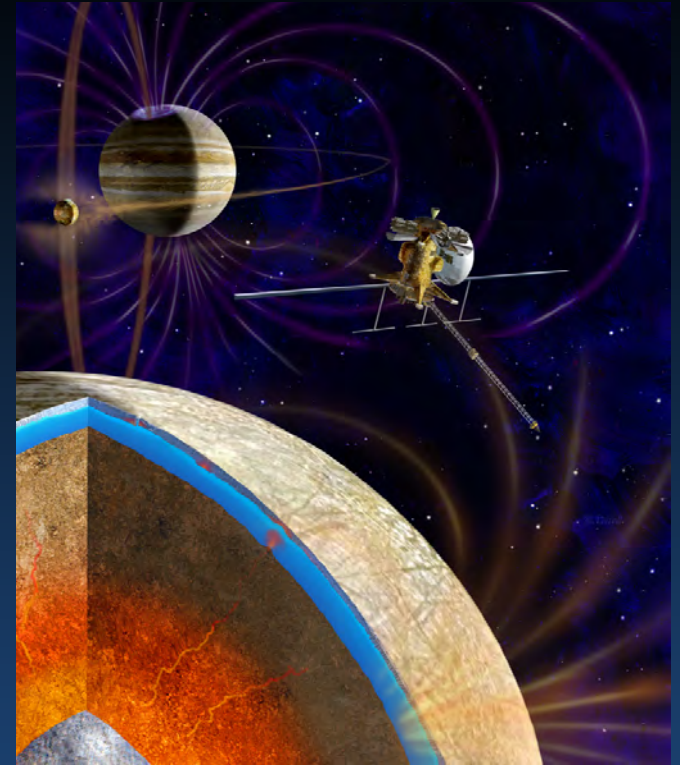
- Ocean characterization
- Surface-ice-ocean exchange
- Compositional makeup
- Geological evolution
- Jupiter system science
 - Galilean satellite evolution
 - Sat. atmospheric interactions
 - Magnetospheric physics
 - Jupiter atmosphere
 - Ring system dynamics

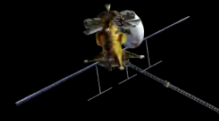
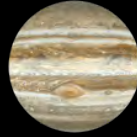
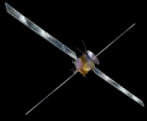
Rich and robust science of Europa and the Jupiter system



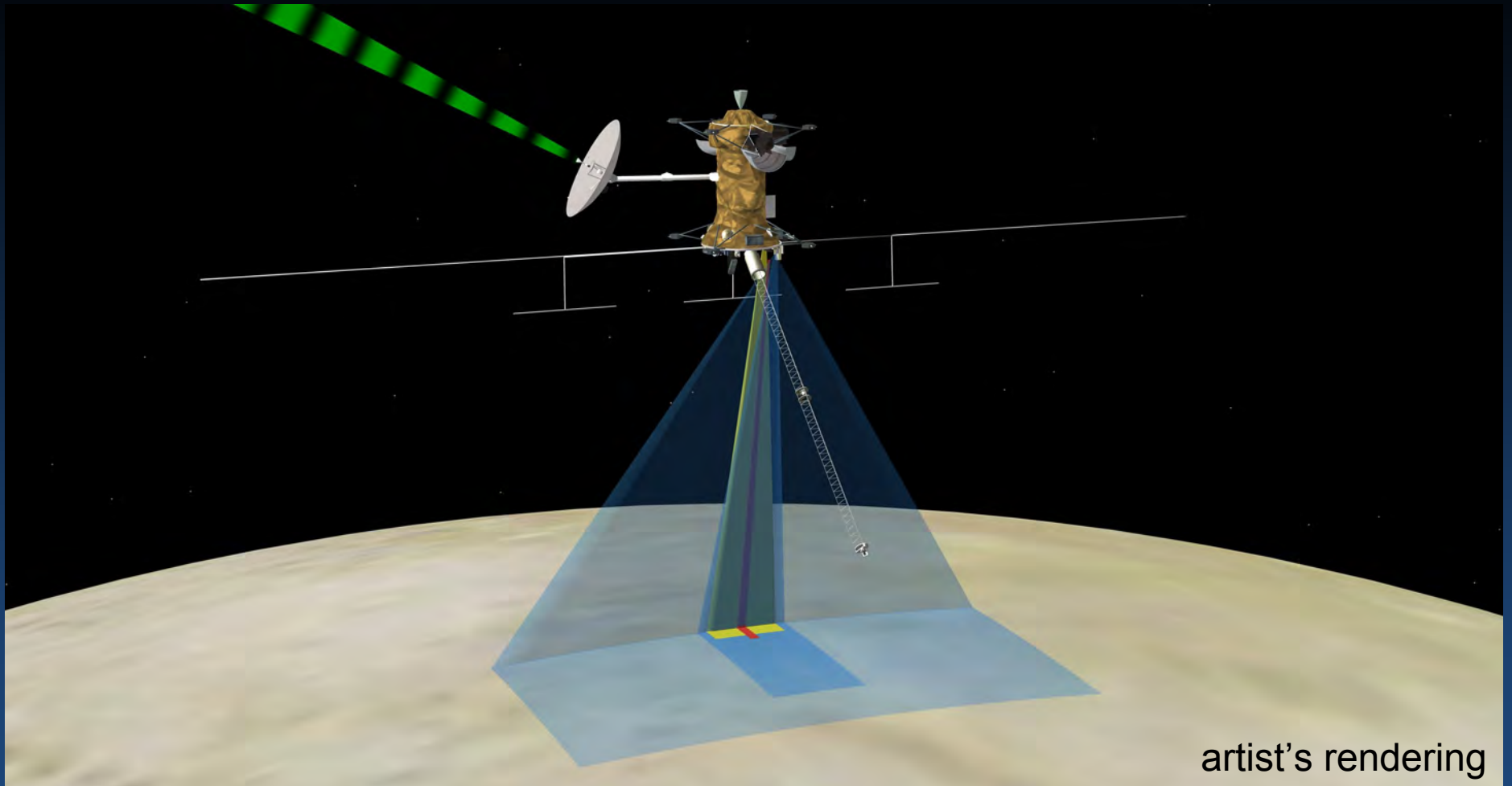
JEO Baseline Mission Overview

- Launch vehicle: Atlas V 551
- Power source: 5 MMRTG or 5 ASRG
- Mission timeline:
 - Launch: 2020
 - Jovian system tour phase: 30 mo.
 - Europa orbital phase: 9 mo.
 - End of prime mission: 2029
 - Spacecraft final disposition is Europa impact
- Radiation dose: 2.9 Mrad (behind 100 mils Al)
 - Handled using a combination of rad-hard parts and tailored component shielding
 - Key rad-hard parts are available, with the required heritage
 - Team is developing and providing design information and approved parts list for prospective suppliers of components, including instruments



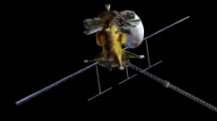
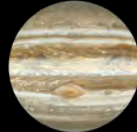
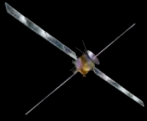


Orbital Operability

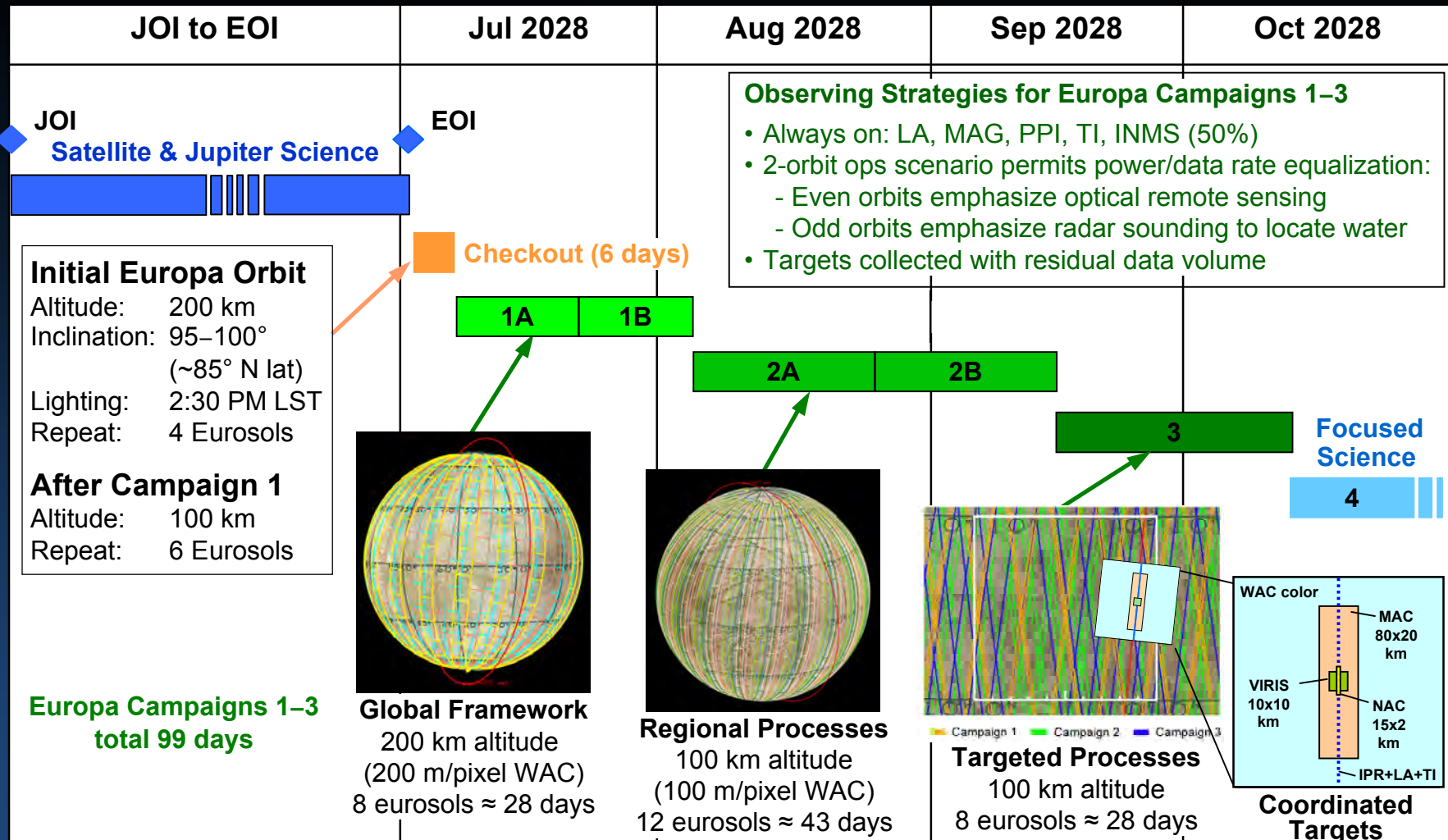


artist's rendering

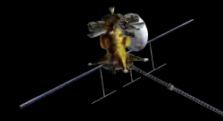
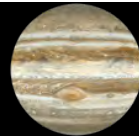
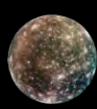
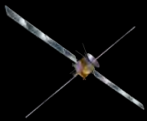
Articulated antenna would permit simultaneous observations and downlink



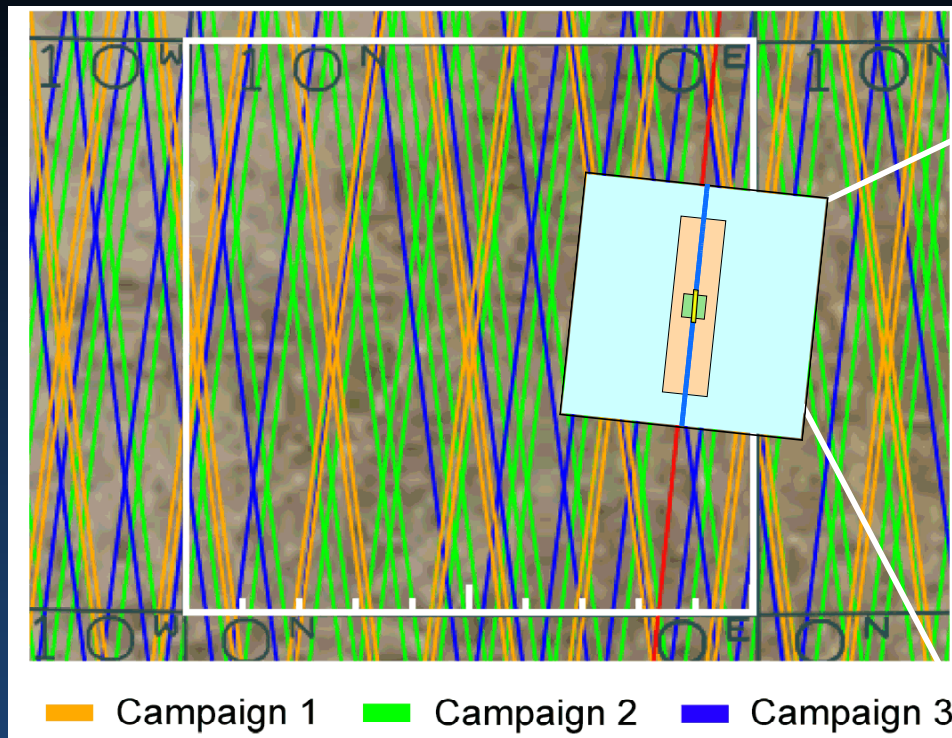
Europa Science Campaigns



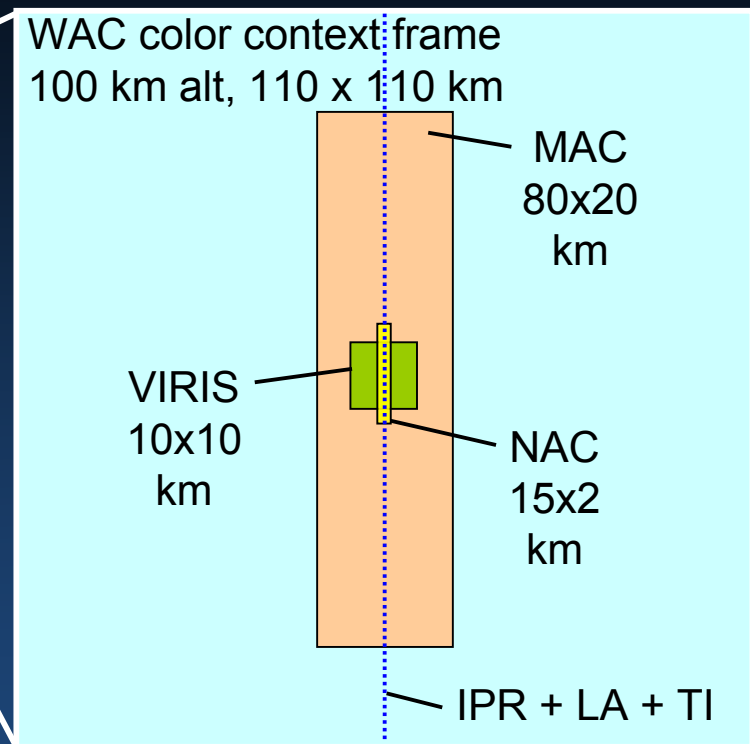
Europa science objectives addressed in first 100 days in orbit



Europa Science Campaigns: Profiling and Targeted Observations

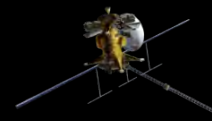
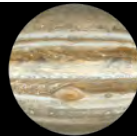
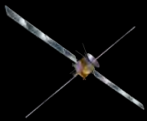


≤18 km groundtrack separation after 100 dy

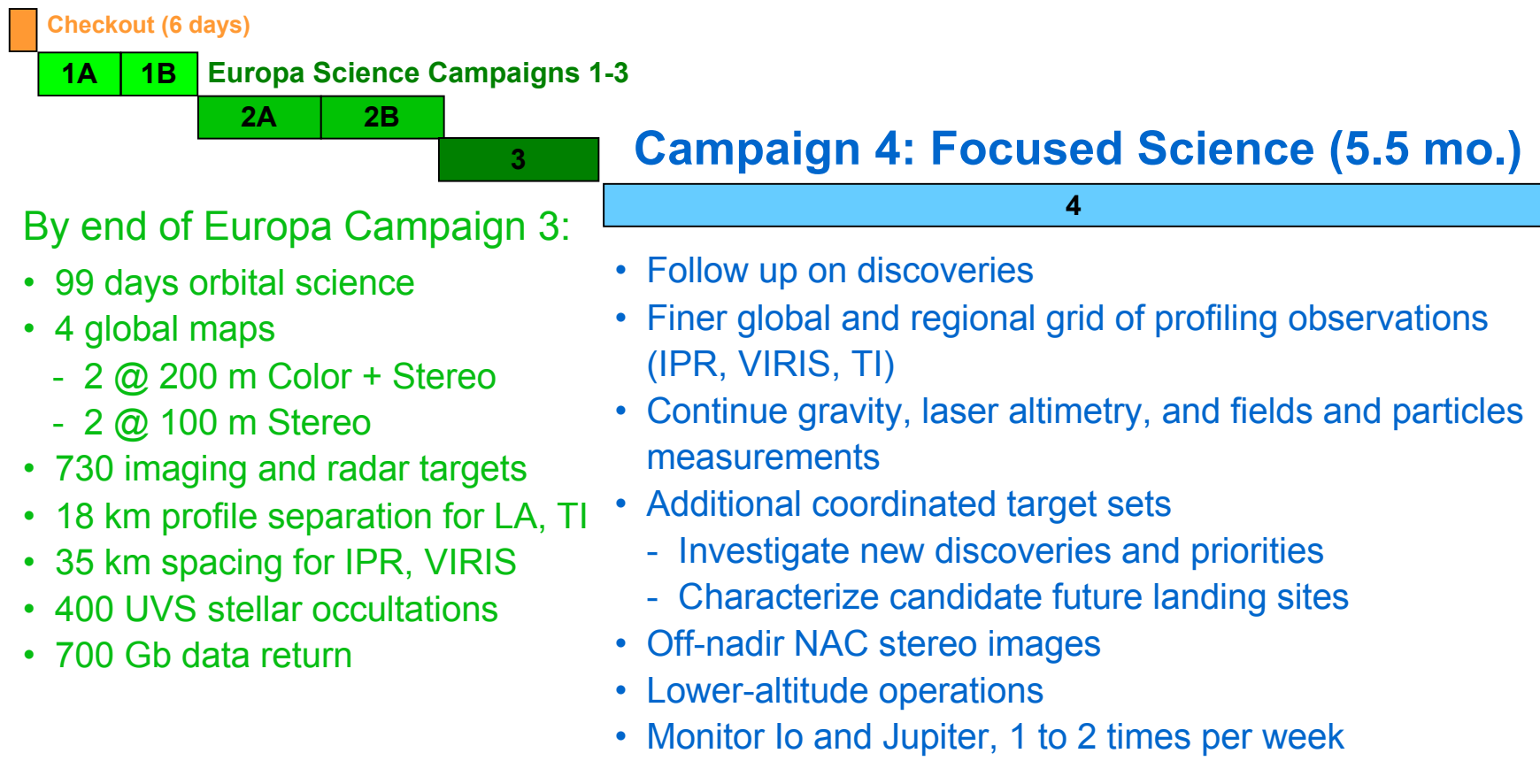


290 Mb coordinated targets

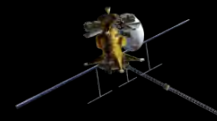
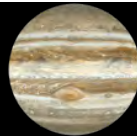
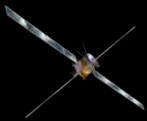
~1700 coordinated targeted observations obtained after 9 mo.



Europa Science Campaigns

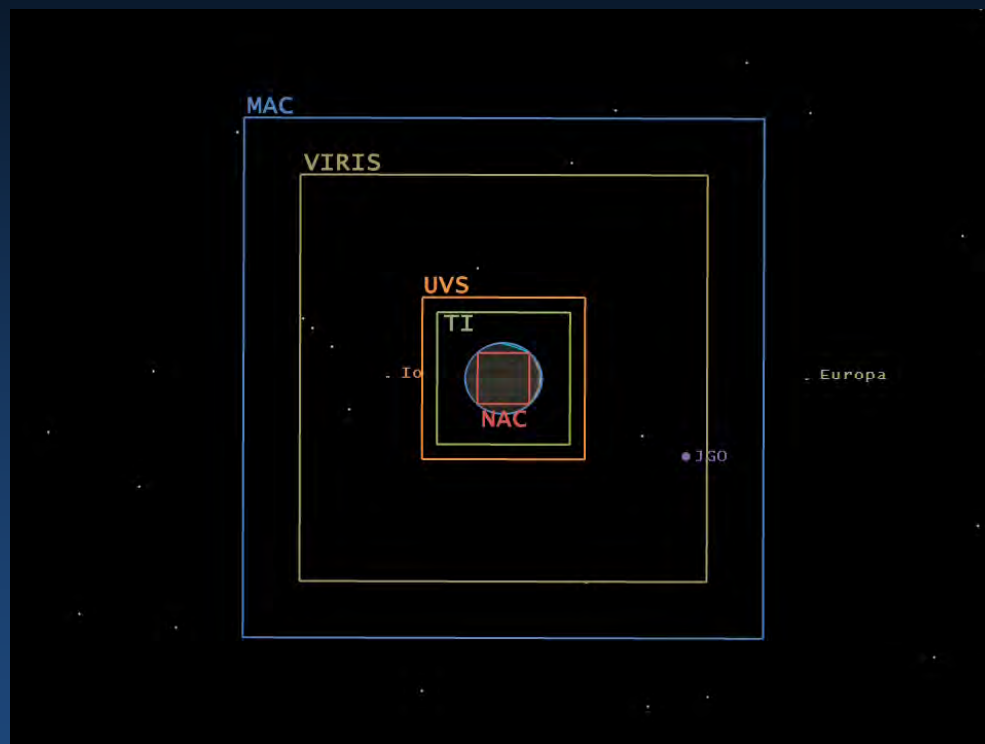
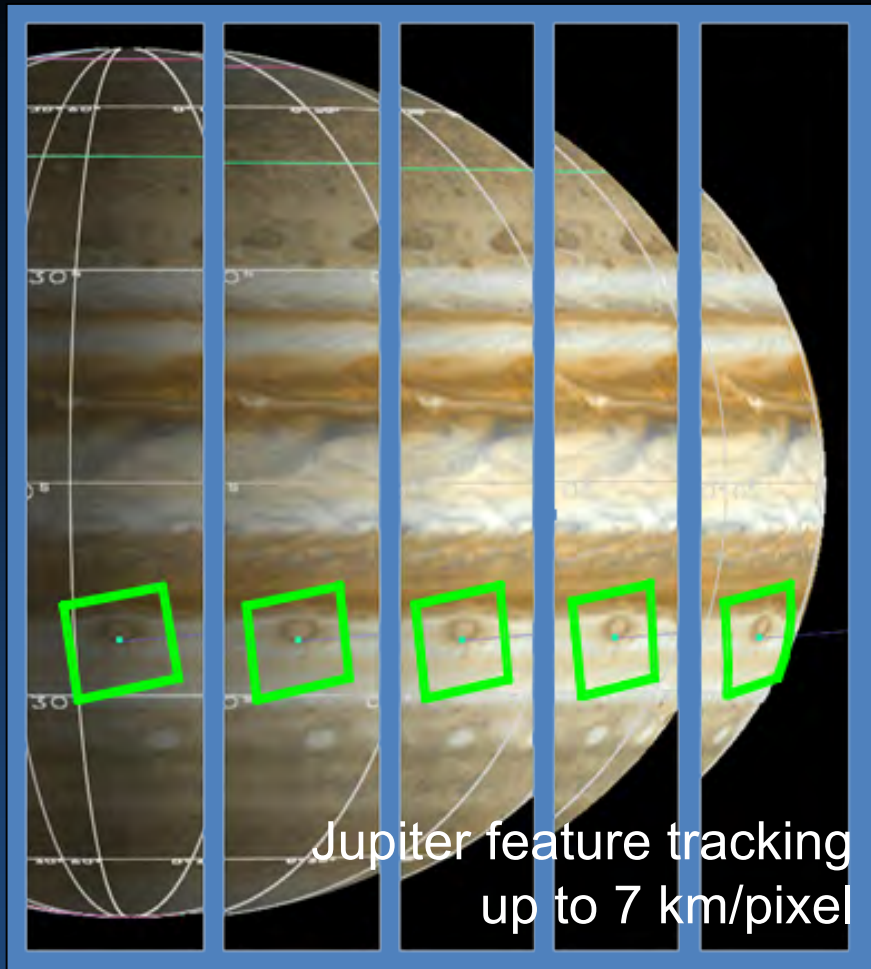


Focused Science Campaign would allow follow-up on discoveries

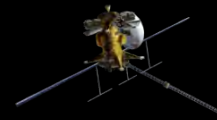
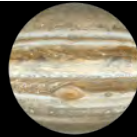
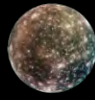
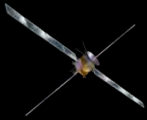


Jupiter System Science

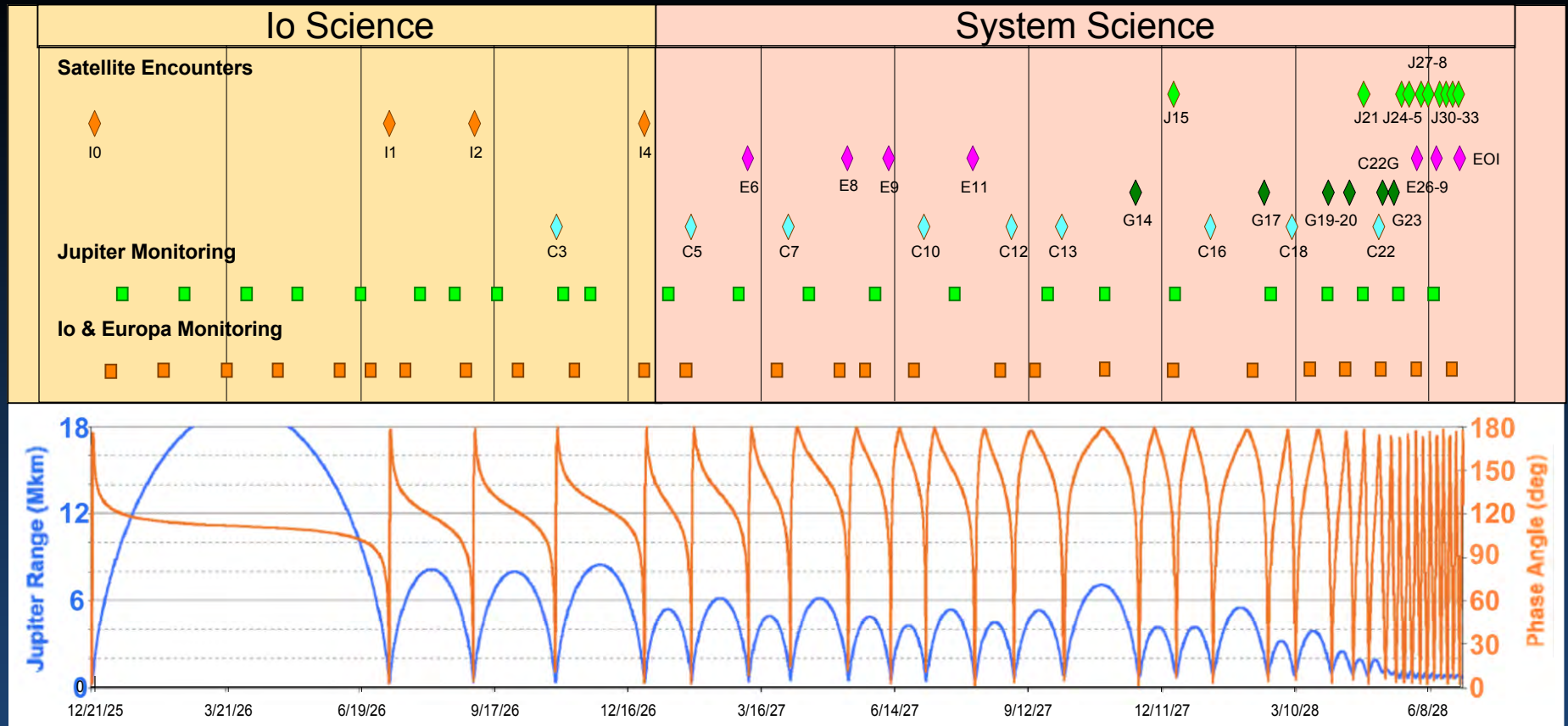
- ~25 Gb collected each perijove
- ~3.2 Tb available during Jovian tour
- ~1000 times Galileo data return



Jovian Tour would enable in-depth Jupiter system exploration

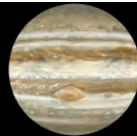
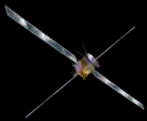


Jovian Tour Example

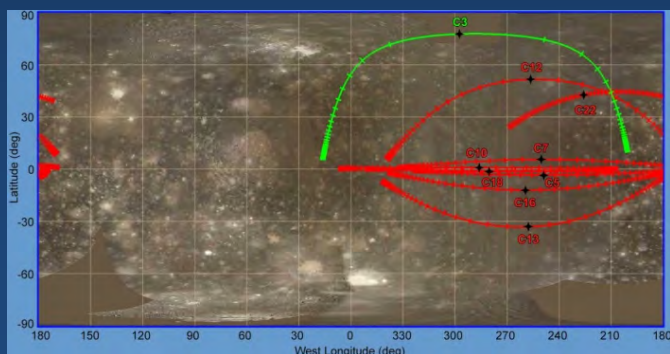
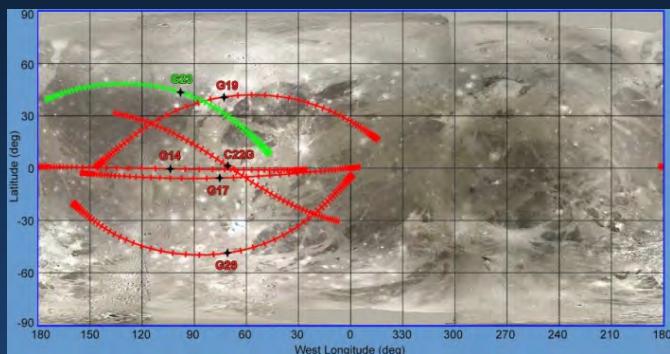
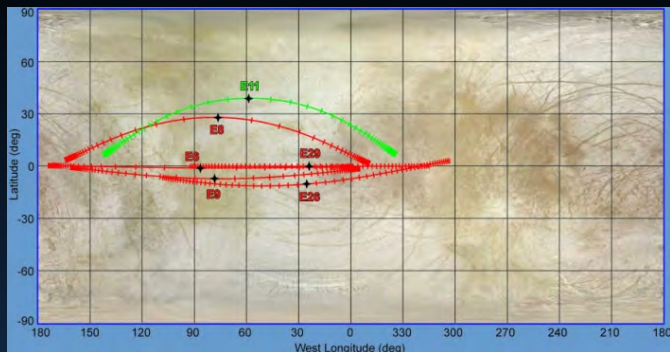


- 33 perijoves during example Jovian Tour

Rich opportunities to acquire Jupiter System science

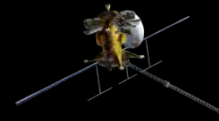
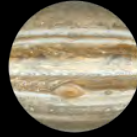
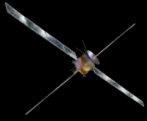


Jovian Tour Satellite Science

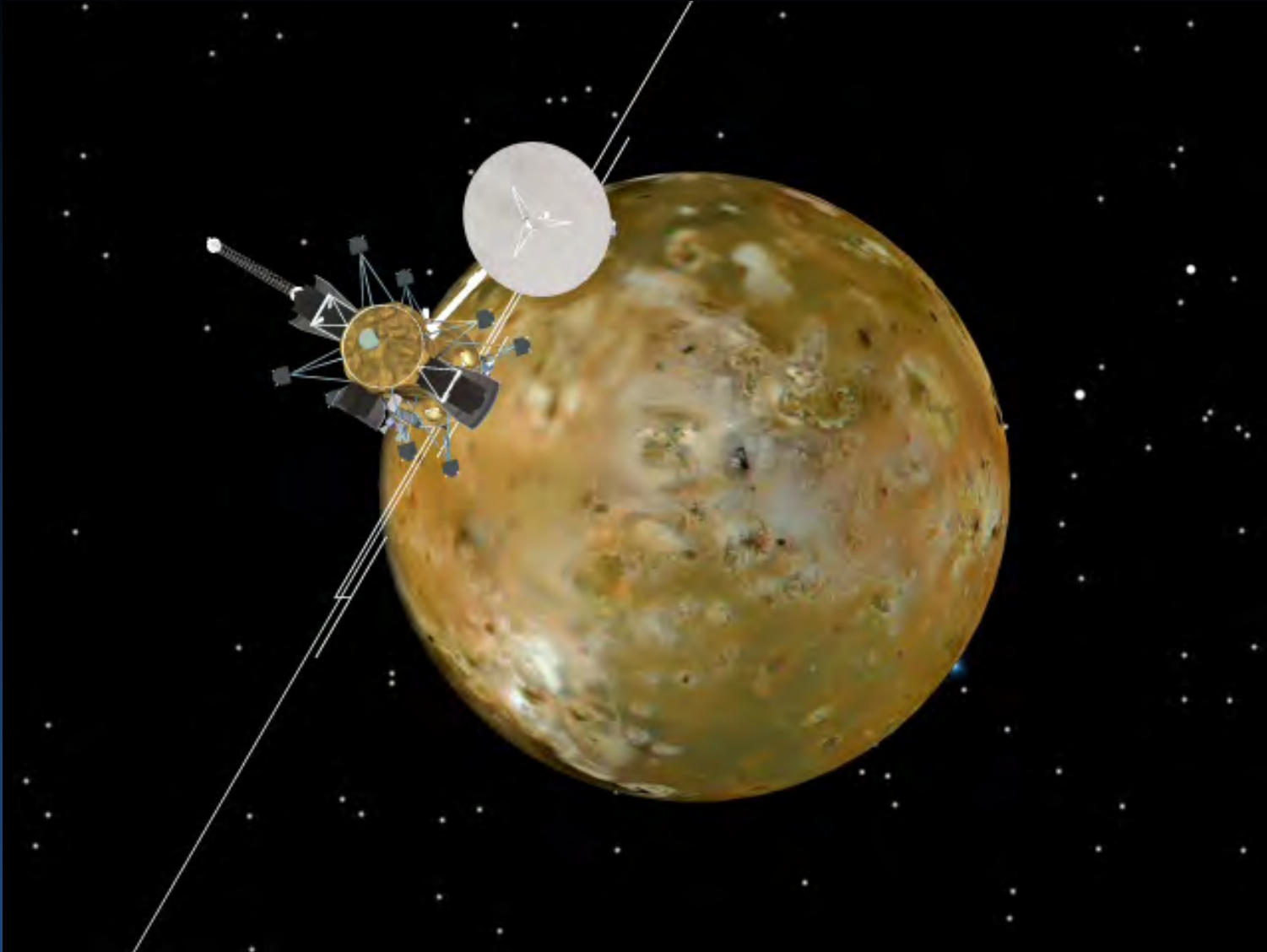


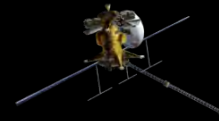
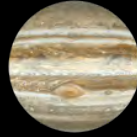
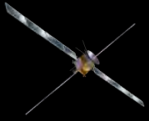
- Io: 3 flybys
 - Opportunities for imaging, IR spectroscopy, and altimetry
 - *In situ* analysis of extended atmosphere with INMS at 75 km
- Europa: 6 flybys
 - Radar and altimetry characterization and calibration
 - Imaging at up to 10–50 m resolution, NIR 250–1250 m
- Ganymede: 6 flybys
 - Radar sounding of grooved and dark terrains
 - Range of lats, lons for magnetosphere sampling
- Callisto: 9 flybys
 - High-latitude flyby for gravity field determination
 - Ocean characterization with magnetometer
 - Radar for subsurface structure of ancient cratered terrain

Satellite	≤1000m	≤200m	≤50m	≤10m	Length IPR (km)	Length LA (km)
Io	30%	20%	5%	-	1000	7400
Europa	60%	60%	15%	0.01%	6600	19000
Ganymede	50%	50%	10%	0.02%	17000	28000
Callisto	85%	75%	5%	0.01%	15000	30000



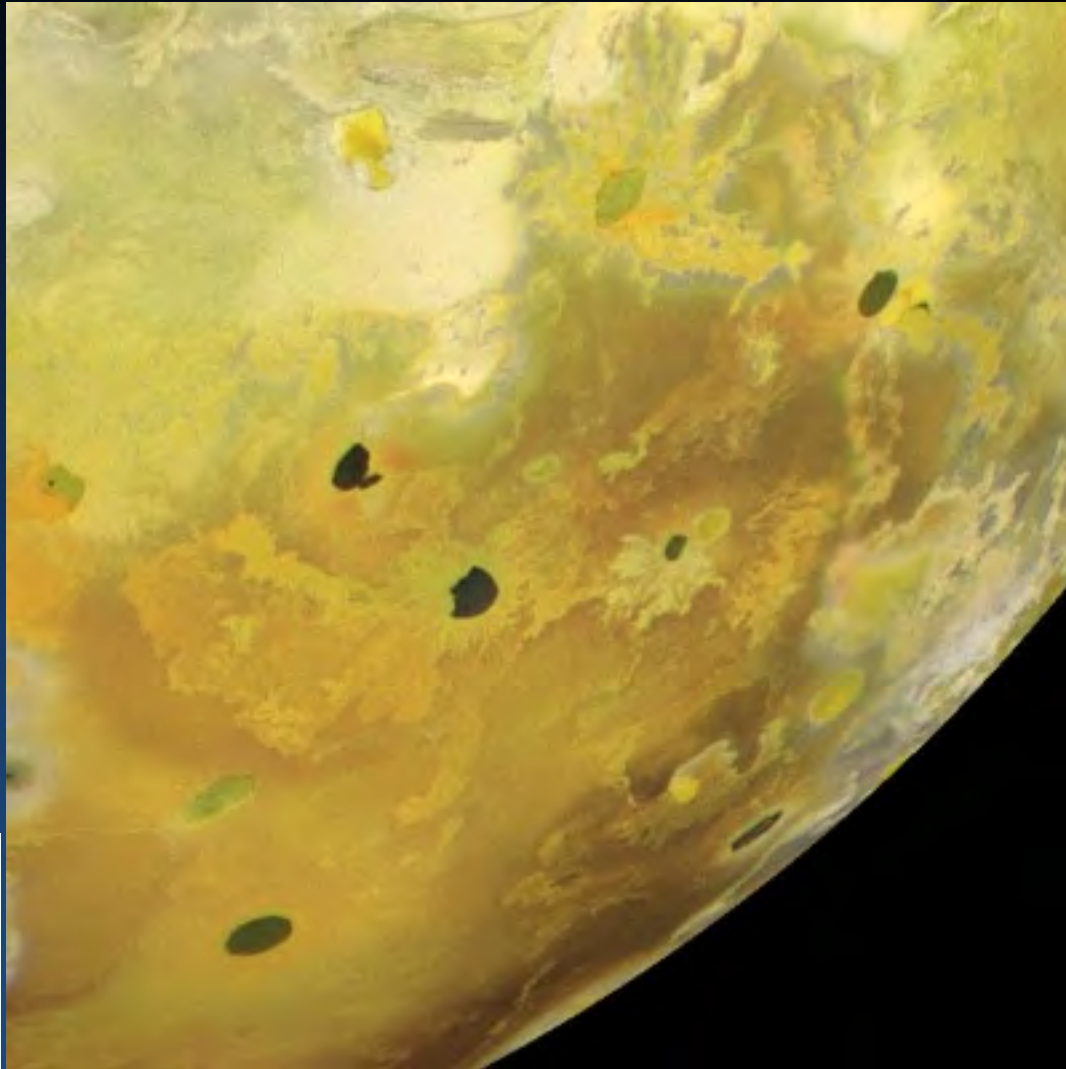
Io Flyby Example



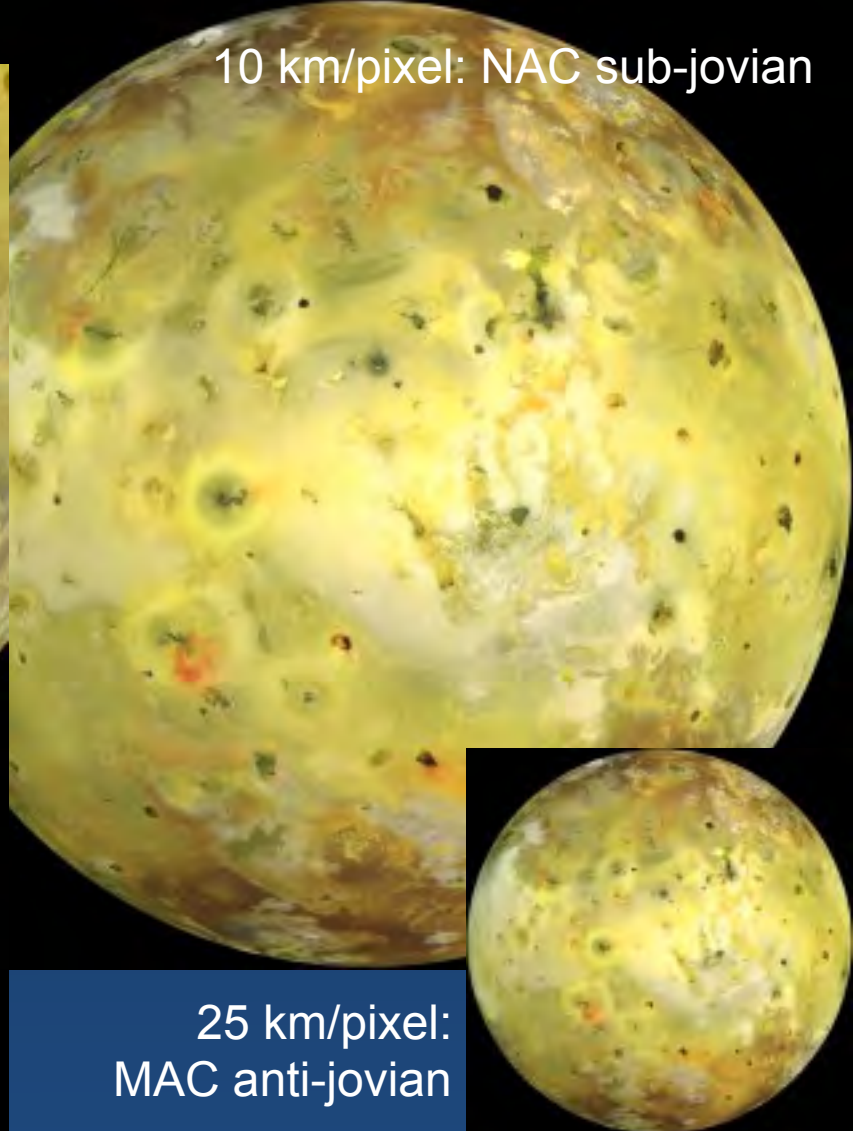


Io Resolution Examples from Europa Distance

2.5 km/pixel: NAC anti-jovian

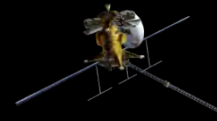
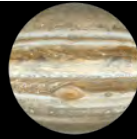
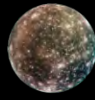
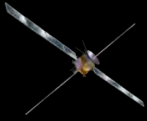


10 km/pixel: NAC sub-jovian



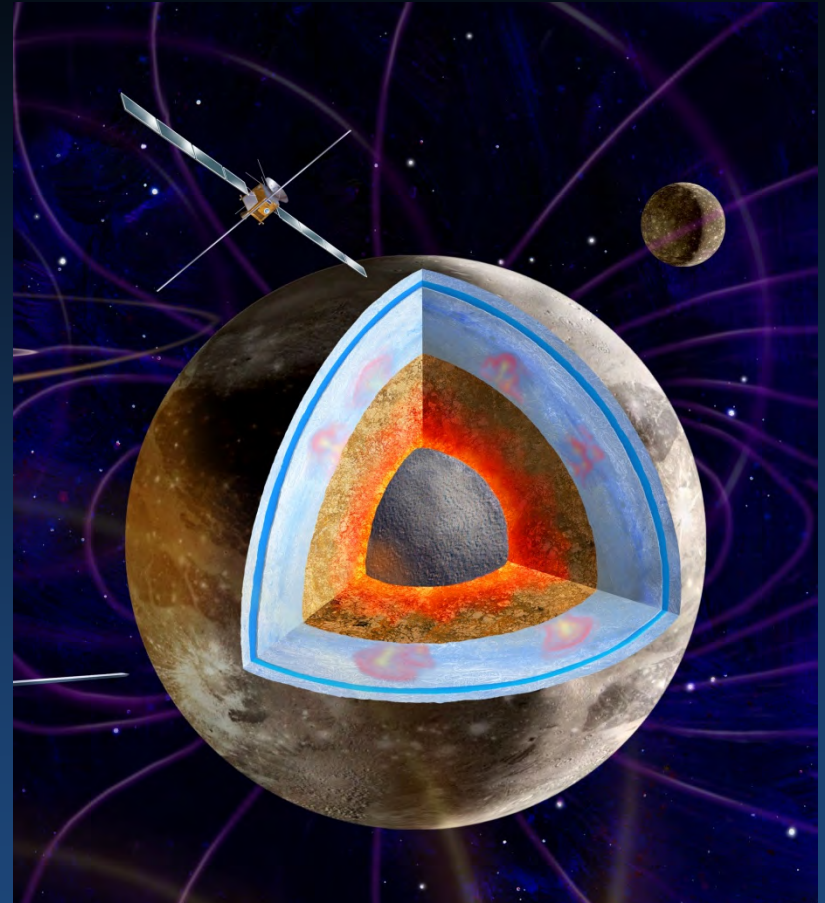
25 km/pixel:
MAC anti-jovian

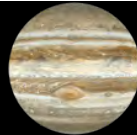
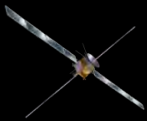




JGO Science: Overview

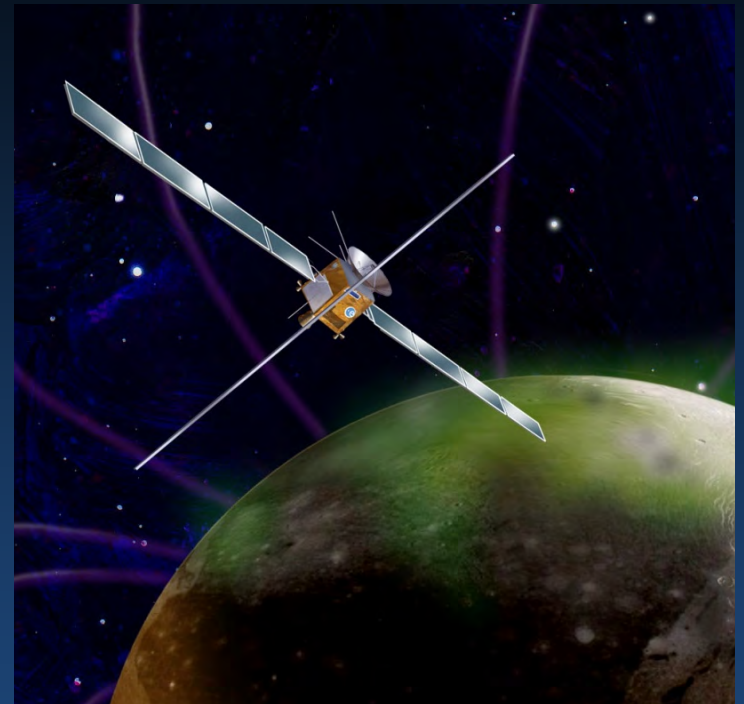
- Key JGO science phases
 - **Jupiter system:** In-depth exploration
 - From Jupiter orbit, synergistically with JEO
 - **Callisto:** In-depth study and mapping
 - Multiple flybys using a resonant orbit
 - **Ganymede:** Detailed orbital study
 - Elliptical orbit first, then circular orbit
- Science Objectives:
 - **Ganymede:** Characterize Ganymede as a planetary object, including its potential habitability
 - **Satellite System:** Study the Jovian satellite system
 - **Jupiter:** Study the Jovian atmosphere
 - **Magnetosphere:** Study the Jovian magnetodisk / magnetosphere
 - **Jupiter system:** Study the interactions occurring in the Jovian system

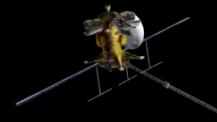
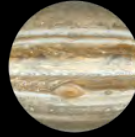
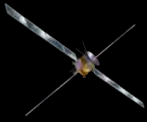




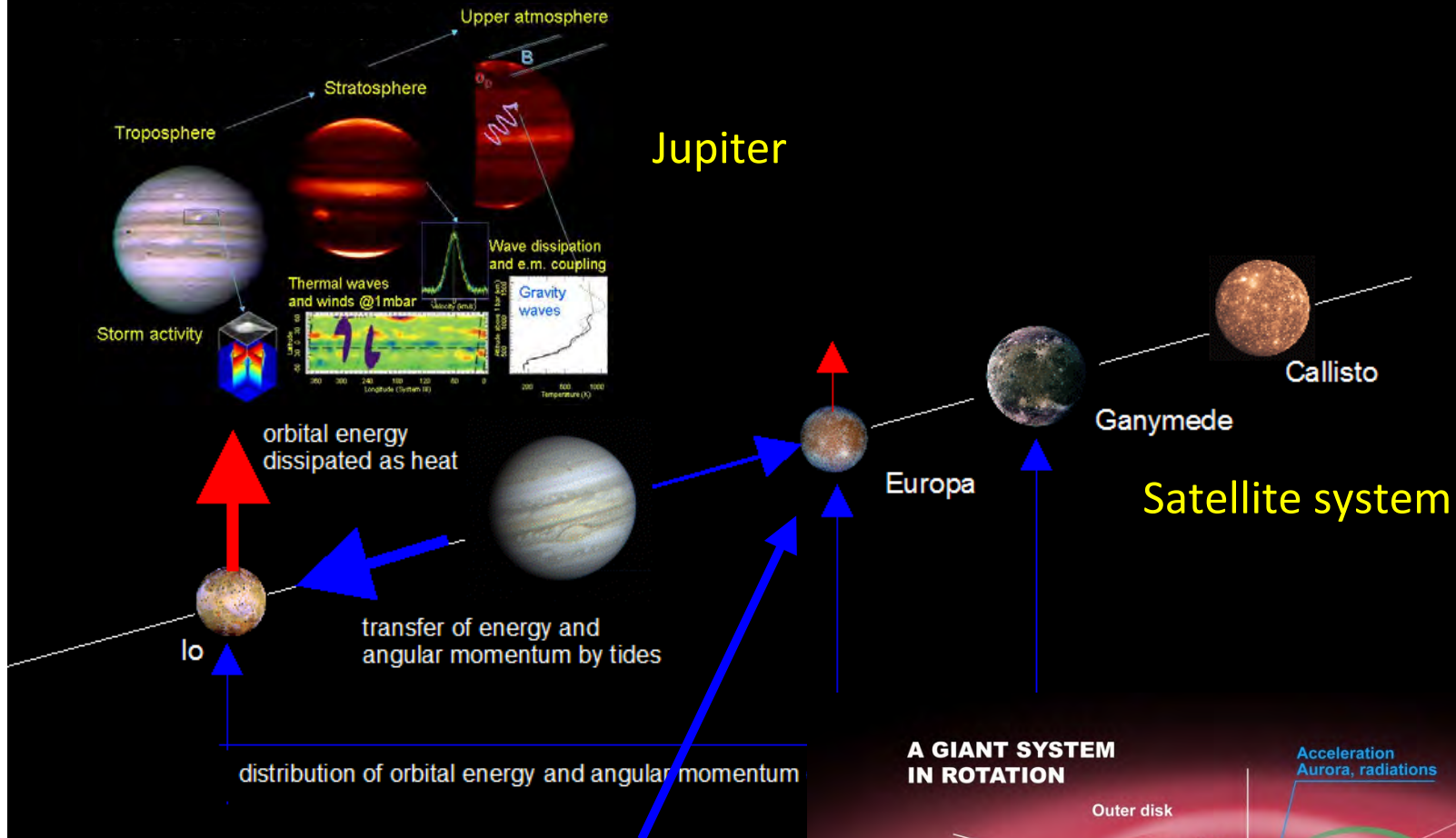
JGO Payload Definition Document (PDD) Study Model Payload

PDD Model Instrument Name	Acronym
Medium-Res Camera & Wide Angle Camera	WAC+MRC
Magnetometer	MAG
Radio Science Transponder and USO	JRST+USO
Visible InfraRed Hyperspectral Imaging Spectrometer	VIRHIS
Plasma Package & Ion and Neutral Mass Spectrometer	PLP/INMS
Sub-mm Instrument	SWI
Radio and Plasma Wave Instrument	RPWI
Narrow Angle Camera	HRC
Sub-Surface Radar	SSR
Laser Altimeter	LA
UV Imaging Spectrometer	UVIS

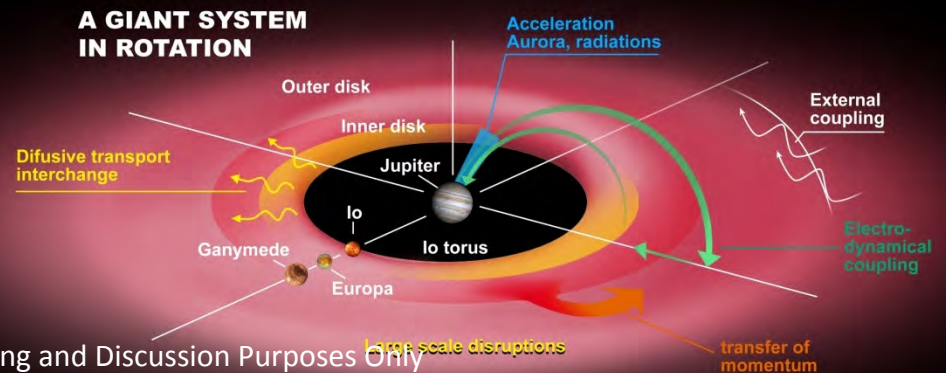


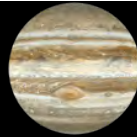
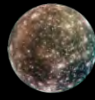
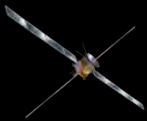


The Jupiter System: Three Coupled Components



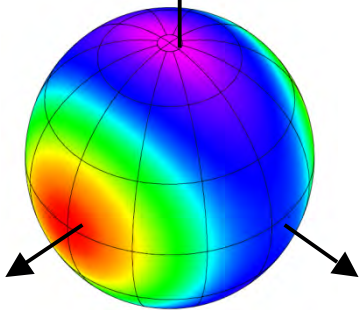
**Magnetodisk/
radiation belts**





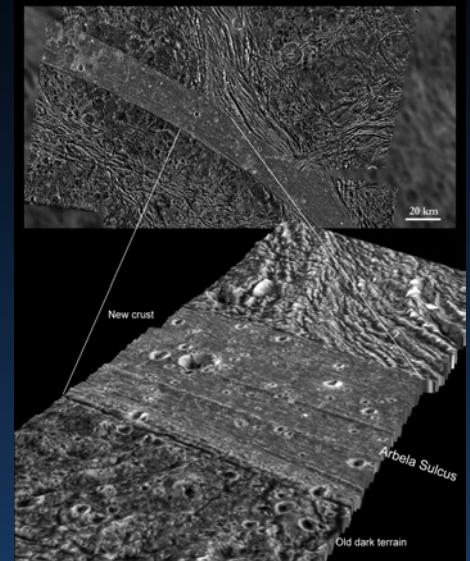
Ganymede: Europa's "False Twin"

Tidal deformation

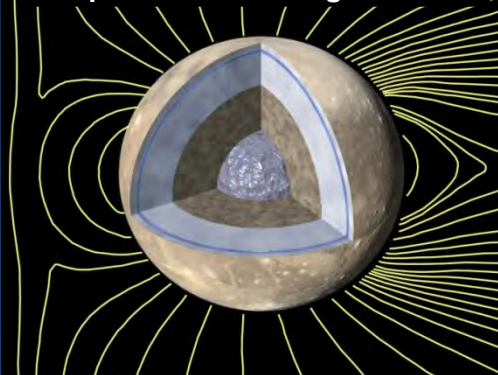


- Presence and extent of a subsurface ocean
- Ice shell and subsurface water
- Deep internal structure, dynamo, magnetic field
- Coupling among surface, exosphere, and magnetosphere
- Surface composition and chemistry
- Surface features, tectonic processes
- Thermal evolution, geology, and the Laplace resonance

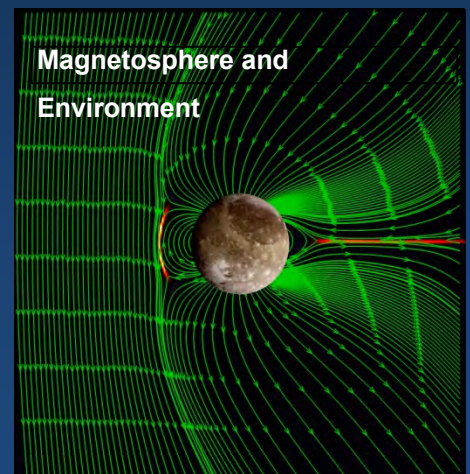
Geology and Topography



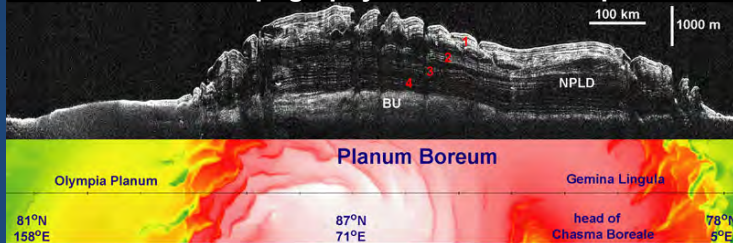
Deep Interior and Magnetic Field



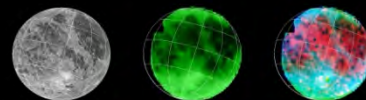
Magnetosphere and Environment

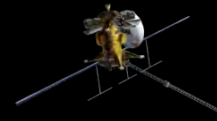
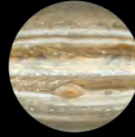
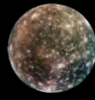
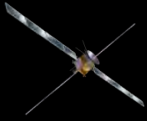


Structure and topography of Mars' Polar Cap



Compositional Differences

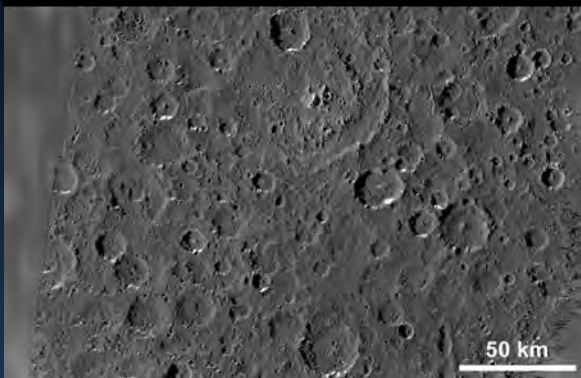




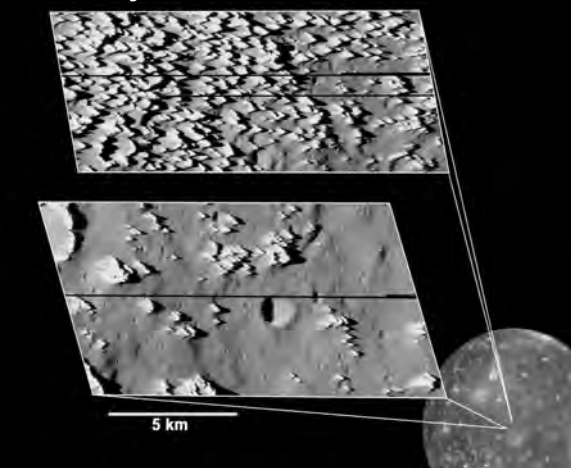
Callisto: A Witness of the Early Ages

- Presence and extent of a subsurface ocean
- Ice shell and subsurface water
- Deep internal structure, including degree of differentiation
- Cratering record and early geological history
- Surface composition, including organics and CO₂
- Surface degradational processes (erosion and sublimation)

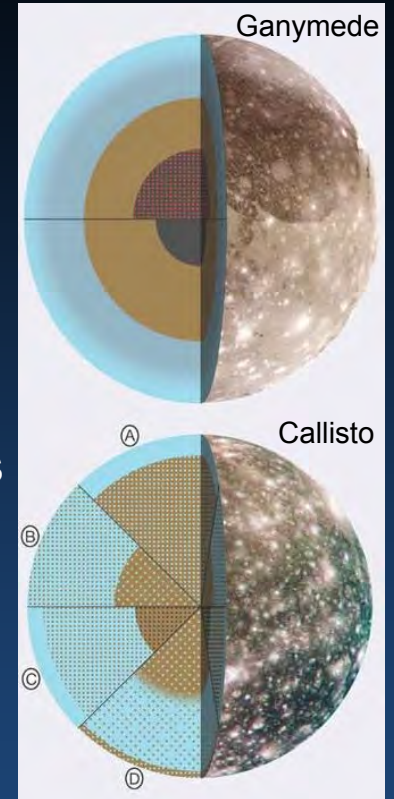
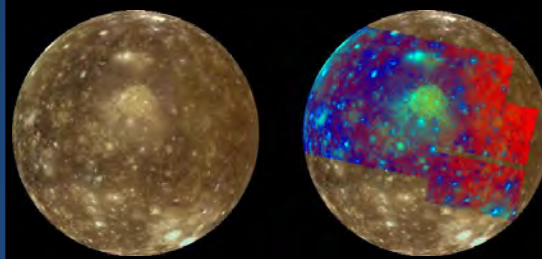
Crater Distribution and Morphology



Knobby Terrain: Erosion Processes

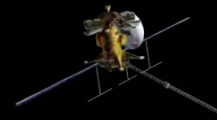
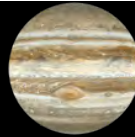
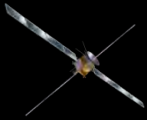


Compositional Heterogeneities

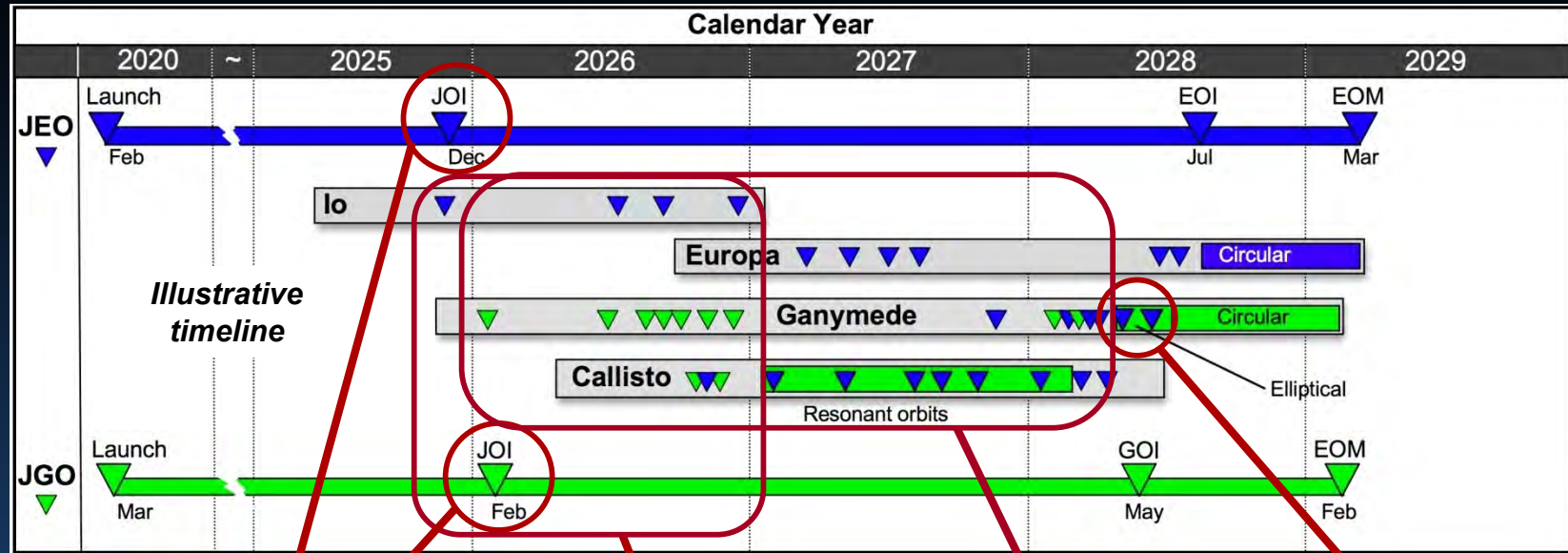


Internal differentiation:
Where is Callisto ?

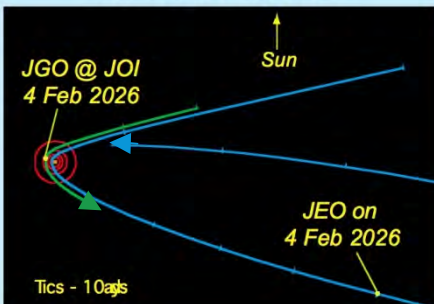
Image after Bagenal et al. [2004]



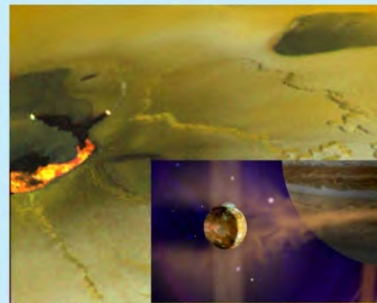
EJSM Synergistic Science



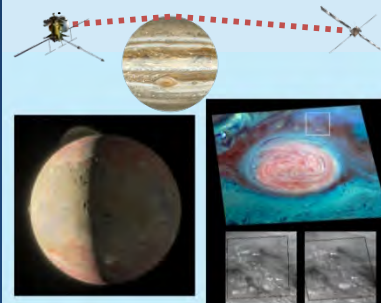
Jupiter Magnetosphere Studies



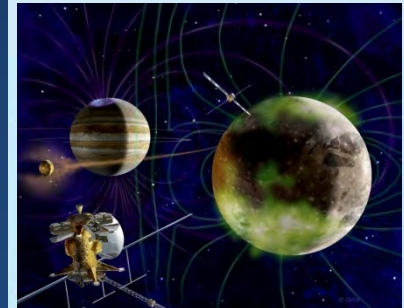
Io Volcanism & Io Torus Dynamics

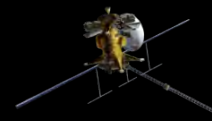
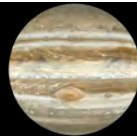
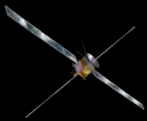


Satellite & Jupiter Monitoring; Radio Occultation Science?



Ganymede Magnetosphere Studies





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California Institute of Technology

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Europa Jupiter System Mission (EJSM)

Jupiter Europa Orbiter (JEO) Concept

Jupiter Ganymede Orbiter Concept

Joint Science Definition Team: Europa-Jupiter

Jupiter Europa Orbiter Radiation and Planetary Protection Tutorials

[Radiation Study Reports](#)

Radiation Study Reports

Read the [Roadmap to Design Guidelines](#) (PDF, 49 KB)

Read the [Radiation Fact Sheet for the Jupiter Europa Orbiter \(JEO\) Mission](#) (PDF, 782 KB)

- Note: Reports forthcoming - pending documentation clearance.

1. JEO Designing Circuits and Systems for Single Event Effects
This document discusses the effects of single energetic particles in space on microelectronic and optoelectronic devices. Examples are provided of the complex responses of advanced microelectronics, including functional interrupts that disrupt the basic way in which devices respond to electrical signals. Various circuit and system design approaches are included.

A wealth of resources are available at the OPFM website

The Europa Jupiter System Mission

